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Contract No. DAMD17-88C-8058

X-Ray System, Lightweight Medical (XRS LM)

Melvin P. Siedband  
Frank C. Grenzow  
Craig A. Heilman  
Robert C. Bruce



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August 10, 1992

Final Report

Prepared For:  
U.S. Army Medical Research and Development Command  
Fort Detrick  
Frederick, Maryland 21702-5012

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## I. Introduction

The contract between the University of Wisconsin and the U.S. Army Medical Research and Development Command , DAMD17-88C-8058 was amended to continue the development of a portable x-ray system. The original concept was developed on an earlier contract, DAMD17-86C-6039. That project saw the completion and demonstration of a small and powerful x-ray system which used electrolytic capacitors as the energy source. Key inventions permitted the design of high power pulse circuits of very small size and weight. That early system was limited to a small x-ray field of 25 x 30 cm and focus-film distance of 70 cm. The work of the current contract was to develop the X-Ray System, Lightweight Medical (XRSLM) based on the technologies of the system of the previous contract. This recent work increased the capacity of the system to permit more general applications. The new design enabled it to cover a full chest of 35 x 43 cm at 100 cm as a free-standing system. The methods developed in the course of this work made possible a considerable reduction of system weight. For example, conventional battery-powered mobile x-ray machines, "batmobiles", weigh about 350 kg while this design weighs less than 90 kg. Unlike conventional mobile x-ray systems, this XRSLM can operate as a free-standing system or used with various litters, tables, chairs and other accessories. Again, unlike most conventional mobile systems, the XRSLM uses a grid for the reduction of the effects of scattered radiation, automatic exposure control and semi-automatic collimation to improve image quality and to reduce the exposure to both patient and operator.

The X-Ray System, Lightweight Medical (XRSLM) is intended for use as a general purpose x-ray system. The system is compact and stored in four containers until ready for assembly. It is designed on the principle of a photographic flash gun where a bank of electrolytic capacitors accumulates energy for several seconds and is discharged to make a fast and powerful exposure. Unlike a conventional 10 kWp system, which would require line power capacity of 10 kW, the XRSLM requires less than 0.2 kW input power and can operate on an internal battery when the power line fails or is not available. Battery-powered mobile x-ray machines overcome the limitations of power lines but the batteries are quite heavy. The XRSLM may be assembled, transported and positioned by one operator. It is designed for use with conventional flat radiolucent tables and litters or operated as a free-standing chest radiographic device. It may also be used with common chairs or dental chairs for head and dental radiography. The mechanical configuration is similar to that of the Basic Radiological System (BRS) of the World Health Organization (WHO). The system is powered by rechargeable NiCd cells or from 110 vac power lines. Automatic exposure control, a fixed grid and

adjustable collimator make possible exposures of the proper density and of clinical quality with minimum exposure to both patient and operator. The configuration of the system is shown in Figs. 1-a, 1-b, and 1-c.

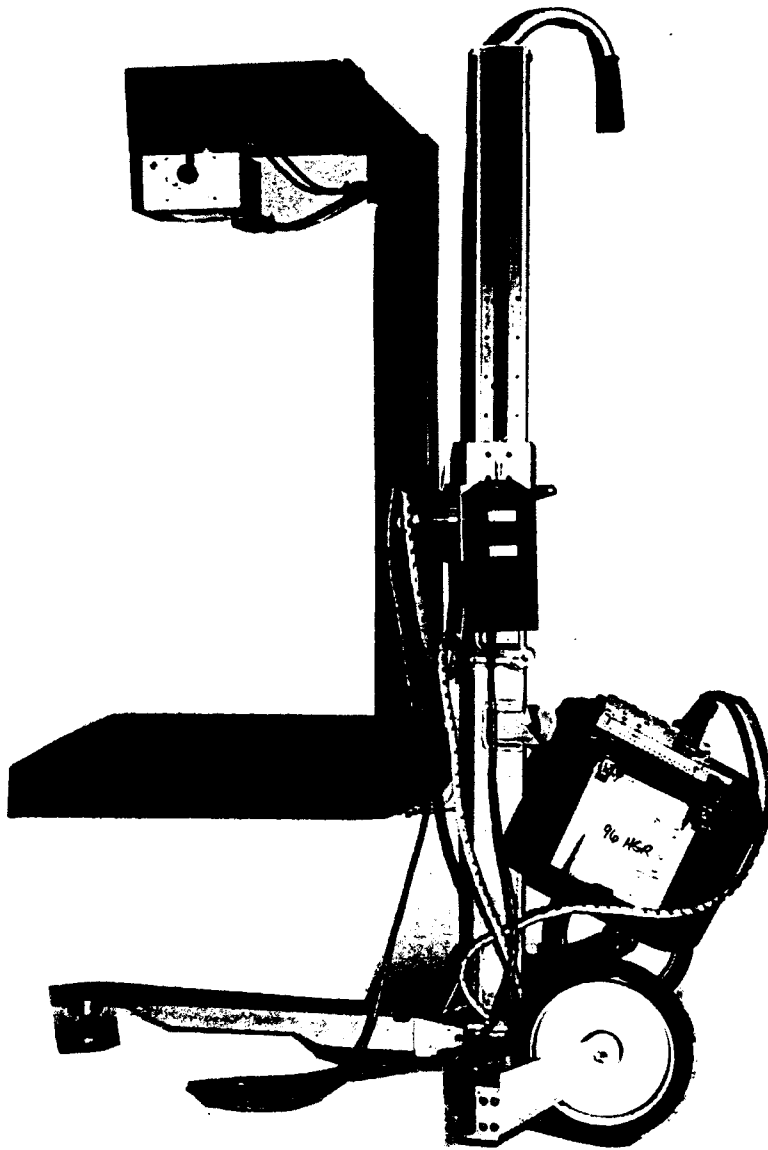


FIG. 1-a. XRSLM with cross arm positioned vertically for under the table type procedures, and for easy transport by tilting unit back onto wheels.

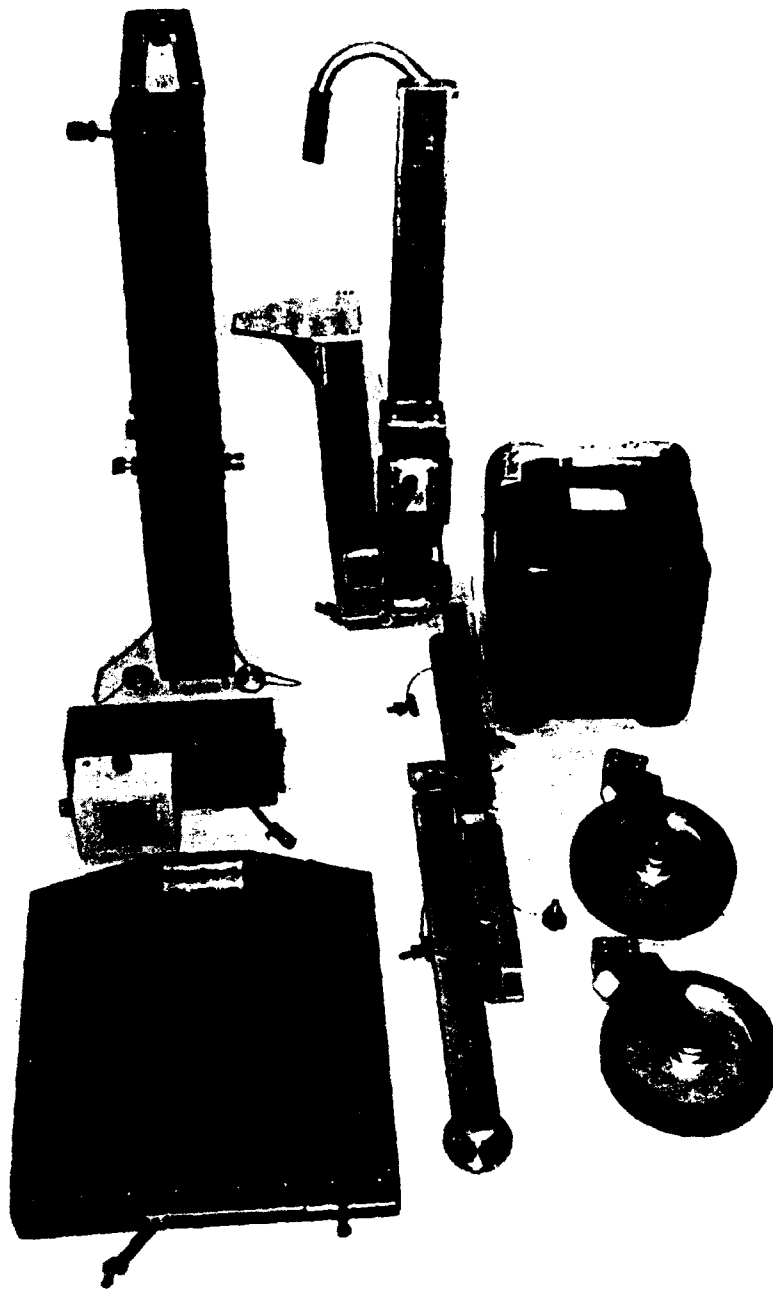


FIG. 1-b. XRSLM disassembled into the major components for packing into the shipping containers.

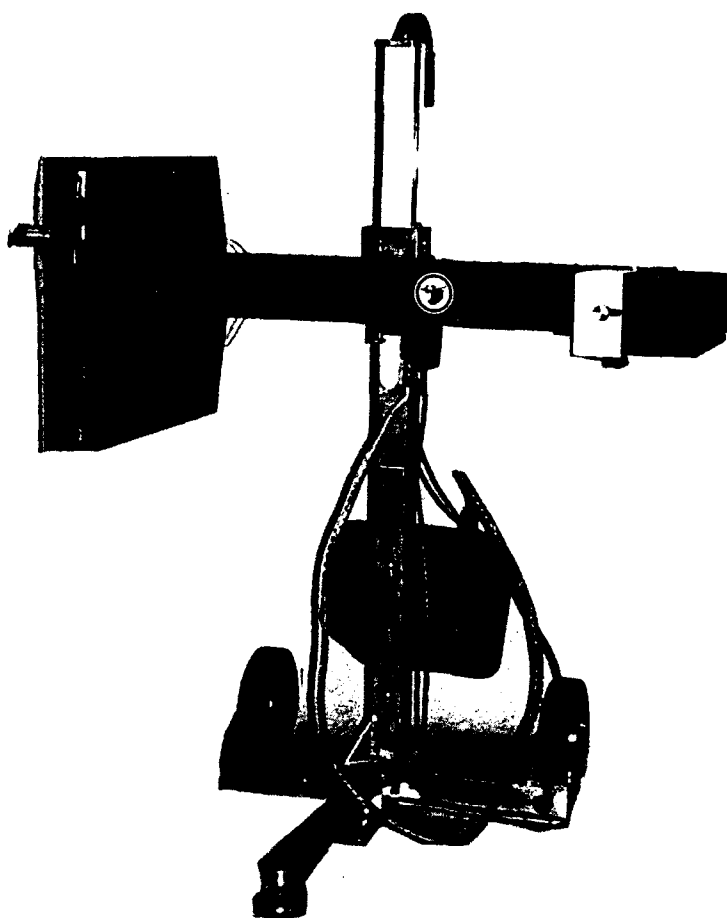


FIG. 1-c. XRSLM with cross arm positioned horizontally for cross-table, chest and head procedures.

One prototype was assembled and laboratory testing was underway at the end of the contract period. A second prototype was completed except that the cassette holder had not been wired and a high voltage breakdown problem in the tubehead had not been resolved. All other circuits have been assembled and tested and work as described in the following sections of this report. The high voltage failure within the tubehead does not appear to be a fundamental problem but would require that a clear plastic model be made to see where the breakdown is taking place in order to make corrections to the design. High voltage circuits operating in volumes as small as the tubehead are quite sensitive to subtle design changes, both electrical

and spatial. Recent tests indicate that the ceramic capacitors may have to be changed to another type. The tubehead is required to work at up to 110 kVp and, to provide a margin of safety, should be tested to 115 kVp. The tubehead did perform well until capacitor breakdown occurred at just over 90 kVp. Drawings, sketches and programming software for the microprocessor are complete to the point where a manufacturer could determine a schedule and costs of production devices.

The design effort was a joint activity of the U.S. Army Medical Research and Development Command, the U.S. Army Medical Materiel Development Activity (both at Ft. Detrick, MD) and the University of Wisconsin. In general, the electrical work was done at the University of Wisconsin and the mechanical work done at Ft. Detrick.

## II. Purpose

The XRSLM is intended for use as the primary radiographic system in situations where small size and transportability are required. Power demands are small and no special wiring or power generators are needed. It may also function as a back-up for regular x-ray apparatus in larger facilities when sudden increases in patient load saturate the capacity of conventional radiographic systems. The XRSLM can be shipped in four rugged containers and assembled without tools by one person in minutes. When assembled, it is maneuverable by one person over rough ground and transported readily to the application site. It can be used with litters, chairs and tables to provide clinical radiographic capability in less than optimal conditions in the field. It is a full-featured system with automatic exposure control, anti-scatter grid, capable of accepting four cassette sizes, adjustable collimation, 100 cm focus-film distance and constant anode potential. The constant potential at the anode increases the efficiency of x-ray production which permits the use of a small, fixed anode x-ray tube and also results in a narrow beam energy distribution for minimum exposure to patient and operator. Exposure factors and the appearance of the radiographs will be the same as conventional radiographs. At least twenty-five exposures can be made from internal NiCd cells. Line-powered operation requires input power levels of less than 0.2 kW, far less than the 10 to 20 kW or more of a conventional x-ray machine of similar capability. Special power generation facilities are not required. The assembled weight is less than 90 kG with all accessories. The operation is simple and conventional and can be learned by a technologist in minutes.

### III. General Description

The assembled system is shown in Figs. 1-a and 1-c. It consists of a vertical support column, base extension, cross arm assembly with the tubehead and cassette holder, power unit and control/display. The power unit and control/display may be hooked to the vertical column for convenient transport. The vertical column and base employ a handle and wheels so that the system may be tilted back to be moved in the same way as a small dolly. The arm assembly can be adjusted for elevation and rotated for positioning over an x-ray table or chair or set horizontally as a free standing assembly for chest radiography. The system may be partially disassembled by removing the cassette holder for temporary storage in a vertical locker or cabinet until required for use.

#### A. Mechanical Configuration

The vertical column assembly uses a hand crank for setting the carriage height. A tapered dovetail mortise on the carriage accepts the rotating bearing and lock of the cross arm assembly. The cross arm assembly contains the power circuits of the x-ray generator and has the tubehead mounted on one end and the cassette holder on the other. The tubehead contains the x-ray tube and its associated high voltage circuits. An adjustable collimator is mounted on the tubehead. The cassette holder has an adjustable mechanism for accepting four cassette sizes with the largest in two positions. An anti-scatter grid and ion chamber sensor for automatic exposure control (AEC) are mounted in front of the cassette position. The grid rejects scattered radiation to improve image contrast. The ion chamber functions in the same manner as the electric eye of a photographic camera and is used to terminate the exposure when sufficient radiation has reached the cassette to make a correct exposure. A lead sheet within the rear cover of the cassette holder is part of the radiation protection of the system. This serves as a beam stop to attenuate radiation. The power unit contains the energy storage capacitors, NiCd cells, battery charger, line-operated power supply, main power switch, circuit breakers, capacitor charger, and has storage compartments for the cables and the control/display. The control/display contains the microprocessor, the liquid crystal displays (LCD's) for the exposure settings, and switches for setting the factors and making the exposure.

## B. Electrical Circuits

The main power is 12 vdc provided by NiCd cells or a line-powered supply. Changeover from cells to power line is automatic. A battery charging circuit provides a small charging current whenever the system is connected to the power line. Charging takes 14 hours when the cells are completely dead and the charger may be left on continuously without harm. The cells will self-discharge about 15%/week. The system uses an inverter to charge four 0.02F electrolytic capacitors to 315 vdc, storing 4kJ (4 kilowatt seconds) of energy. During the exposure, the capacitors discharge through a switching regulator so that the diminishing capacitor voltage is converted to a constant voltage pulse. This pulse is fed to a high frequency power inverter for conversion to a square wave alternating voltage of 35 kHz. The output of the power inverter is fed to the tubehead where the high frequency transformer and voltage multiplier convert the high frequency energy to a voltage of 60 kV to 110 kV at the x-ray tube. The filament regulator circuit converts the 12 vdc to a high frequency alternating voltage that feeds the primary of the small ferrite filament transformer in the tubehead. Three turns of high voltage insulated wire are used as the secondary winding and are connected to the filament of the x-ray tube. The filament power is set in the filament regulator circuit to determine the anode current of the x-ray tube. The microprocessor controls the switching regulator to set the anode voltage and exposure time. Sensing switches in the cassette holder control a circuit which selects voltages for comparison to potentiometer voltages in the collimator. The system matches the collimated x-ray field for each different field size and senses that a cassette is in place. The field size of the collimator must be equal or smaller than the cassette film size and a cassette must be in place or an exposure cannot be made. A timing circuit in the collimator permits push-button operation of the lamp for 30 sec. The automatic exposure control circuit is comprised of a flat ion chamber located in front of the cassette, a power supply and an electrometer amplifier-comparator. Electrons are generated in the ion chamber in proportion to the incident x-rays and are collected and amplified. When that signal reaches a preset level, the comparator feeds a signal to the microprocessor to end the exposure.

## C. Compatibility With Other Apparatus

The XRSLM can be positioned over any standard flat bucky x-ray table, litter or any flat, radiolucent surface which affords clearance for the base extension. Operation over a dental or common chair permits imaging of the head and neck in the standard radiograph-

ic positons. The cassette sizes used are standard and in common use. The high power and constant anode potential allows motion stopping images to be taken in most applications. The system power may not be sufficient to do certain procedures requiring exceptional power, e.g., cross-table hips. The orthogonality of the grid to the central ray of the x-ray beam assures the high clinical quality of the images so that there should be no significant differences of x-ray film quality when compared to full-sized systems. The geometry of the system permits it to temporarily replace failed clinical apparatus or to operate independently.

#### D. Use in the Field

The XRSLM can be packed in three or four containers. The most sensitive assembly is the tubehead which should be packed in a special padded container. Each of the major components: base, column, arm, tubehead, and cassette holder, are assembled without the use of tools. The assembled system may be wheeled to the application site and positioned within a few minutes of unpacking. When stored with the cassette holder removed, this can be attached to the cross arm in less than one minute. When space is limited, the unit may be tilted and transported without the cassette holder. However, the system will not operate without the cassette holder in place.

#### IV. Mechanical Components

The general configuration of the XRSLM is patterned after the Basic Radiological System (BRS) of the World Health Organization (WHO). The concept is that a vertical column sets the height of a cross arm having the cassette holder at one end and the tubehead at the other. The rigid alignment of the cassette holder with respect to the tubehead permits the use of a high ratio anti-scatter grid. The assembly can be used as a free-standing system for chest radiography or positioned over different types of tables, litters or chairs for a wide variety of radiographic positions. The system is light weight and easily transported by one operator and capable of use under austere conditions. To accomplish this, the system is demountable for transportation in several packages. The height of the cross arm is adjustable and the cross arm can be rotated to eight different angles and locked in place with a spring-loaded lock pin.

##### A. Vertical Support

The vertical support is a column with the adjustable carriage which receives the cross arm bearing assembly. The column is attached to the wheeled base. The bearing assembly height is set by a hand crank and locking mechanism. The base comprises a tubular structure and a right angle support. An adjustment device on the support is used to compensate for uneven floors or the ground itself. Very large wheels are used so that the entire assembly can be tilted back for transport as a dolly. The oversized wheels also facilitate moving the system over rough or uneven ground or on ramps.

##### B. Cross Arm

The Cross Arm is fabricated as an aluminum rectangular tube containing the bearing assembly, x-ray power circuits, connectors for the power and control cables, end brackets for the tubehead and cassette holder and their connectors. The mounting devices for the circuit boards have multiple spring contacts for the ground planes of the boards to assure very low resistance connections to the metal structure.

##### C. Cassette Holder

The Cassette Holder mounts to one of the end fittings of the Cross Arm. A rack and panel ribbon connector is used to connect the circuits when the Cassette Holder is mounted. The internal mechanism uses a gear and linkage to adjust the cassette tracks for each

size cassette selected. A mechanical stop centers the cassette. Switches sense the size of the cassette and whether a cassette is in place. A high line/high ratio anti-scatter grid is mounted just beneath a protective sheet of phenolic material. The ion chamber is mounted between the grid and cassette. The adjusting mechanism is just behind the cassette and the protective cover with lead shielding is just behind the mechanism. A circuit board, AEC/chamber selector control switch and density potentiometer complete the assembly.

#### D. Tubehead

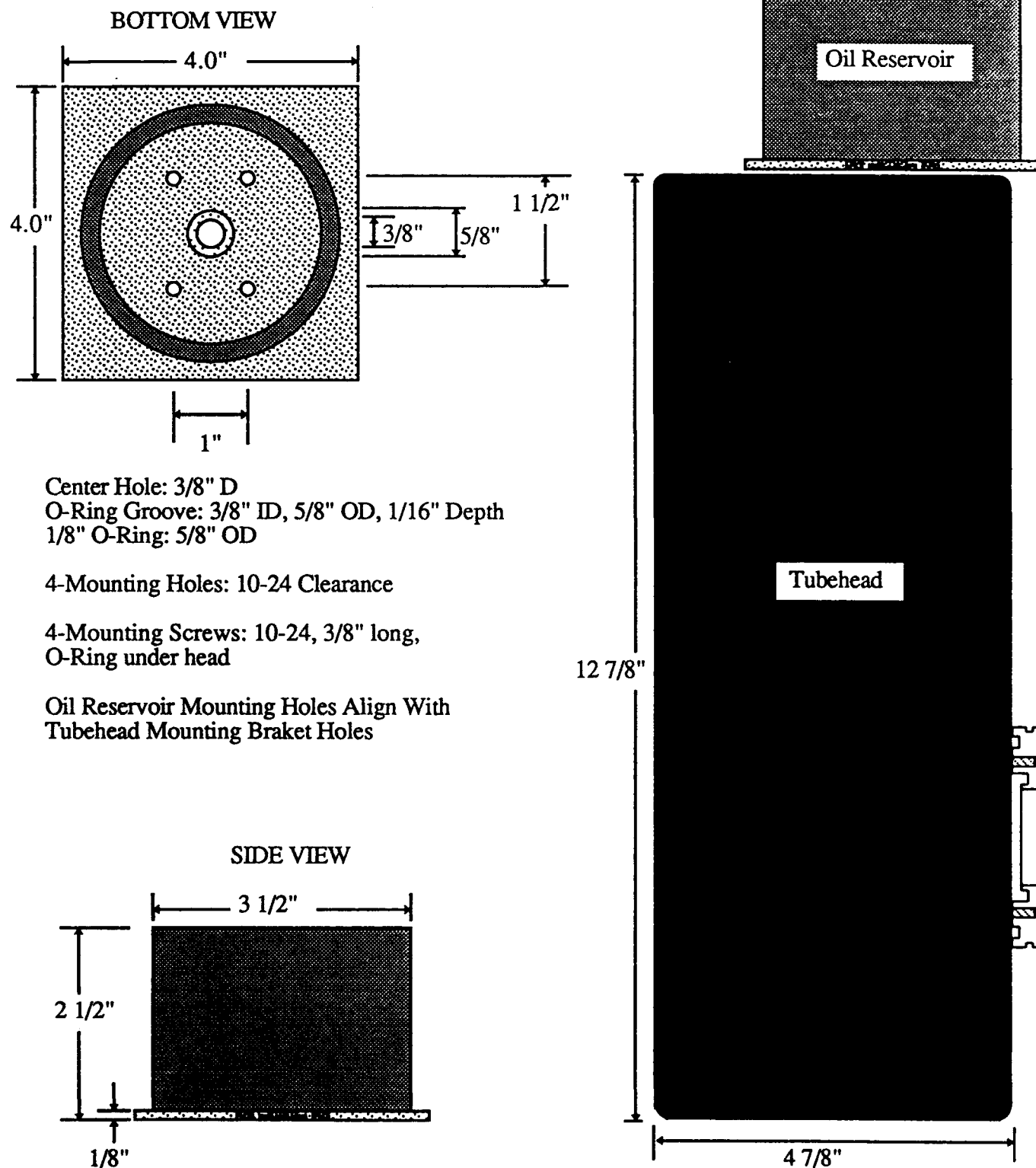
The rigid aluminum casting and cover are bolted together with a Buna-N rubber compression seal similar to a large O-ring. The assembly must be filled with a high grade transformer oil (Shell Diala AX) and placed in a vacuum chamber to preclude the formation of moisture or air bubbles which could destroy the high voltage circuits. Oil filling is done through a special tool shown in Fig. 2. This tool is mounted over the filling plug during the vacuum pumping and the plug is put in place before removing the tool. The pressure in the chamber must be held to below 10 torr (ideally, below 1 torr) for at least 30 minutes. Oil expansion caused by warming during operation can be as much as 4% of the oil volume. A welded metal bellows assembly permits safe expansion of the oil. A measuring tool is inserted in the vent hole of the mounted bellows to verify inside clearance of 2.8 to 3.1 cm when the tubehead is at 20-22 degrees C. The window assembly uses a machined brass port which is O-ring sealed to the housing casting. The window itself is O-ring sealed to the brass port. The collimator is clamped to the assembly and held in place with set screws.

#### E. Control/Display

The circuits including the microprocessor and displays are mounted in an aluminum box with a polycarbonate cover. The four push-button selector switches are assembled to the cover with neoprene protective boots. The two position exposure switch is also assembled with a protective boot. Because medical equipment of this type may be exposed to body fluids and other contaminants, the assembly has been designed so that it can be washed with mild detergents or disinfectants but should not be submerged. A hole in the extended back plate permits the box to be hooked on the column or associated apparatus for ready access. The pendant cable is sufficiently long so that the operator can stand away from the machine to reduce exposure to scattered radiation.

ARMY X-Ray Tubehead Oil Filling Tool  
Fig. 2

Material: Acrylic Tube, 3 1/2" OD,  
1/8" or 1/4" Wall  
Cemented to 1/8" Acrylic Sheet



## F. Power Unit

The Power Unit is designed to remain in its case when used. The case may be hung on a hook on the vertical support for transport or placed in any convenient position for operation. The power unit has a storage compartment for the Control/Display and for the power cables. The main power switch is on the panel of the unit with power indication at the control display. A neon pilot light indicates when the unit is connected to a live power line and does not indicate that the system is turned on. When connected to a live power line and turned off, the pilot light indicates that the NiCd battery is being charged.

## V. Electrical Circuits

The power and capacitor charging circuits are in the power unit; the inverter and x-ray power circuits are in the cross arm; the cassette size and automatic exposure circuits are in the cassette holder; the high voltage circuits are within the oil-filled tubehead; and the control/display contains the microprocessor. The electronic subassemblies are on printed circuit boards. The circuit boards in the cross arm are mounted in spring-loaded tracks. These tracks are essential as grounding devices because the high frequency currents of the power inverter will couple to critical circuits if they are not connected firmly to the chassis. The circuits are connected together via conventional cables and connectors or via simple internal terminal strips. An overview of the electrical circuits is shown in Fig. 3.

**DANGER!!!** Potentially lethal voltages are present in many of the circuits during operation and the capacitor bank may remain charged for several minutes after power has been turned off. Do not attempt to perform any service on the system unless you are familiar with it and have the proper instruments.

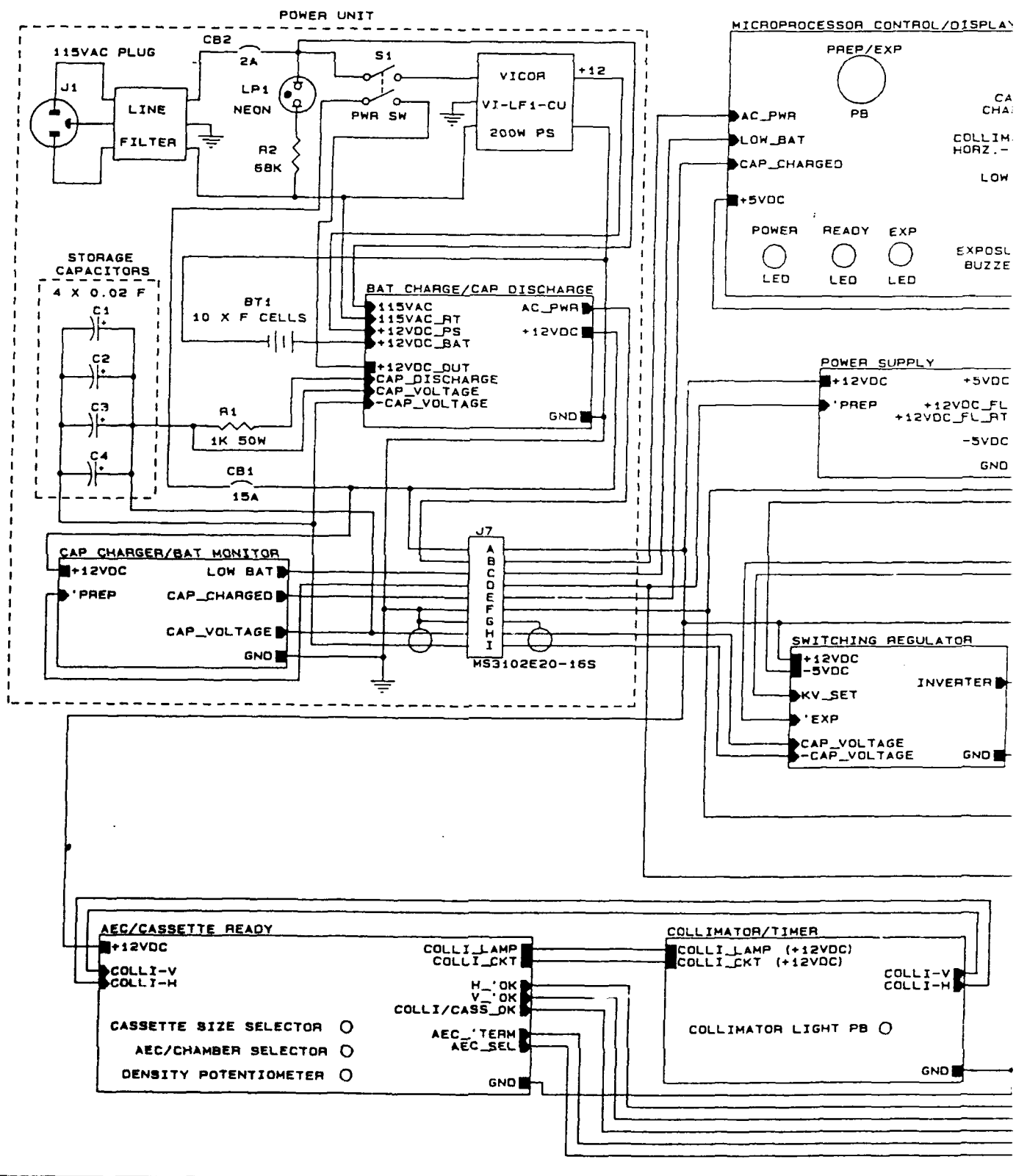
**DANGER!!!** This apparatus produces x-rays which may be dangerous to patient and operator and should not be used unless required by prescription of a physician or unless proper precautions have been taken.

### A. Power Unit

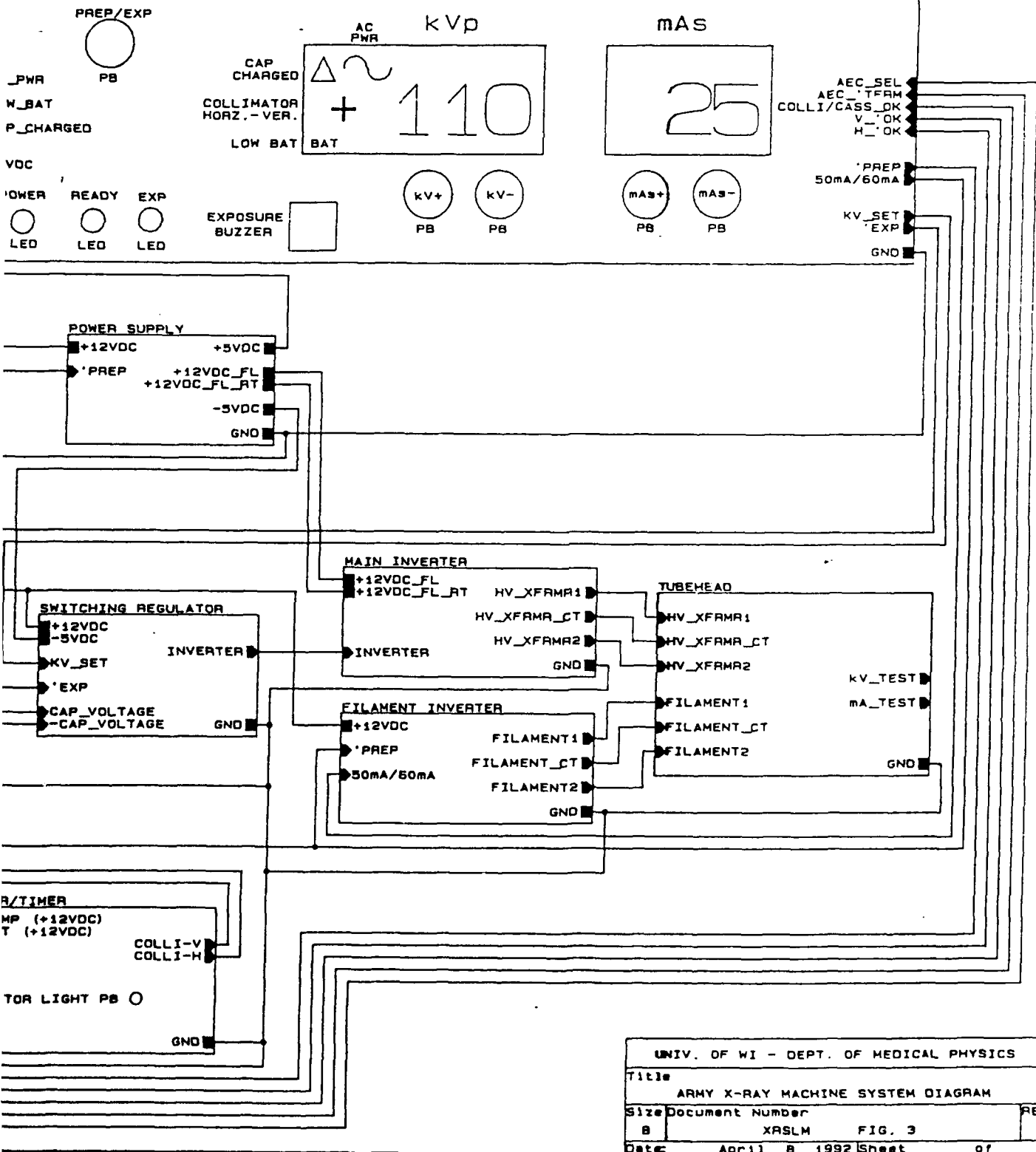
The Power Unit contains the ten NiCd cells, the line power supply, the capacitor bank of four 0.02 F/315 vdc energy storage capacitors, the battery charger, the capacitor charger and the control switches and indicator. The Power Unit case also stores the connecting cable to the Cross Arm and the line power cable; and it has a storage compartment for the Control/Display. Fig. 4, Fig. 5 and Fig. 6 are the schematic diagrams of the Power Unit.

#### 1. Line Power Circuit

The system is connected to a 110 vac power line via a standard power cord and three-prong connector. An internal filter, part of the chassis connector receiving the power cord, keeps external radio frequency signals from disturbing operation of the system. Internal signals which might disturb radio communication are also kept from radiating from the system. A 2A circuit breaker CB2 limits fault currents in the



# ROPROCESSOR CONTROL/DISPLAY



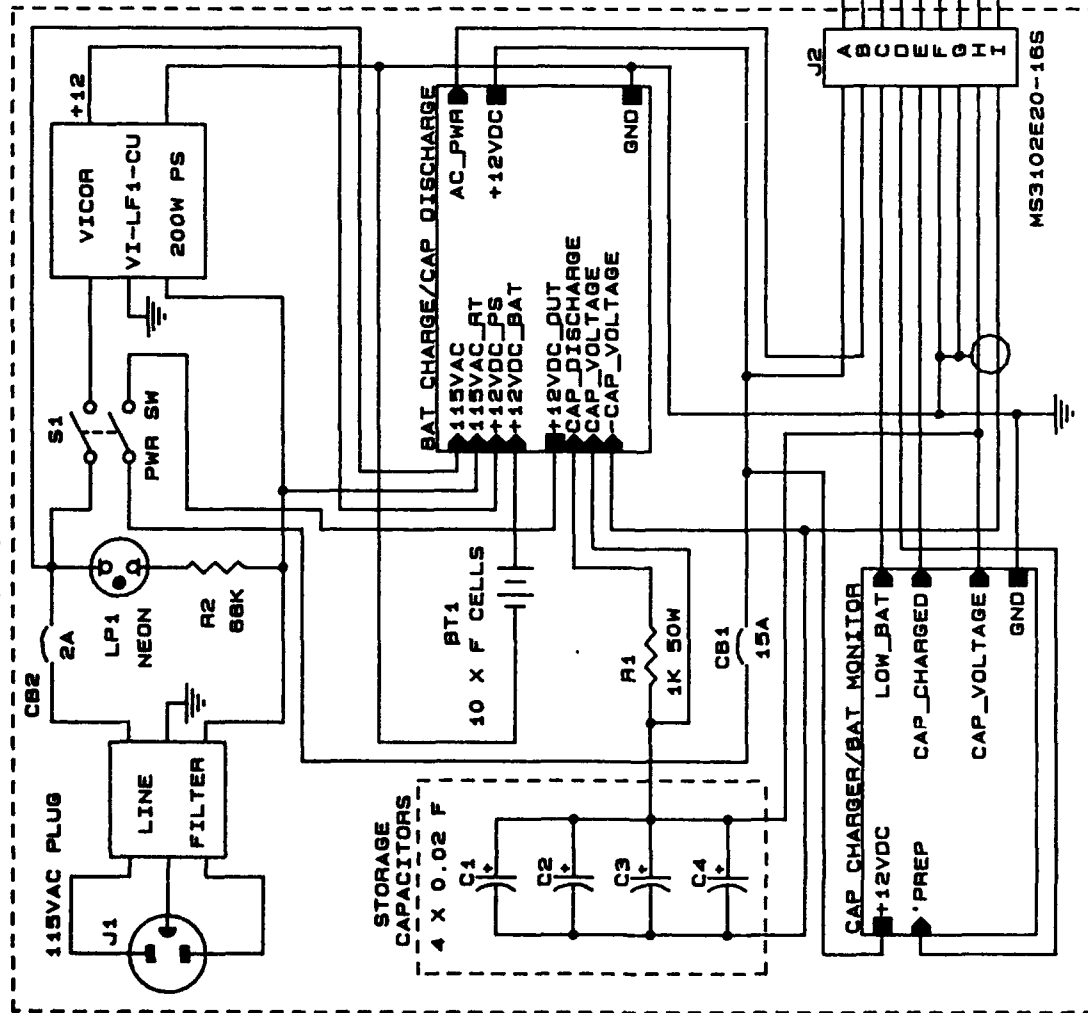
UNIV. OF WI - DEPT. OF MEDICAL PHYSICS

Title ARMY X-RAY MACHINE SYSTEM DIAGRAM

Size Document Number 8 XPSLM FIG. 3 REV

Date April 8, 1992 Sheet of

# POWER UNIT



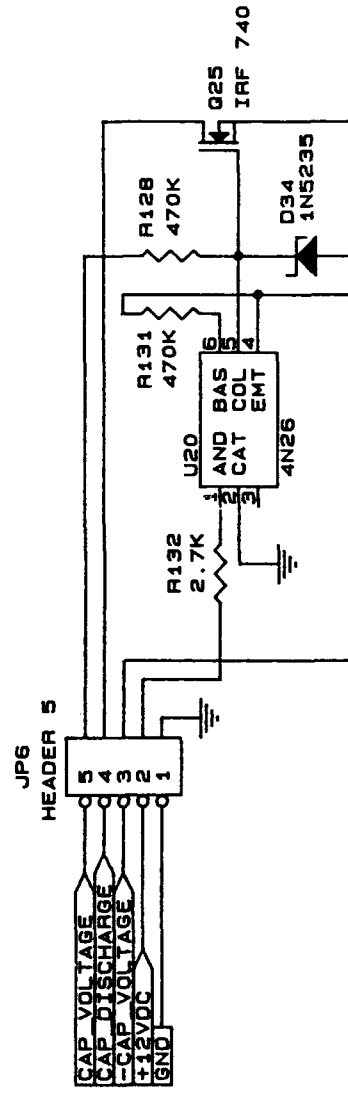
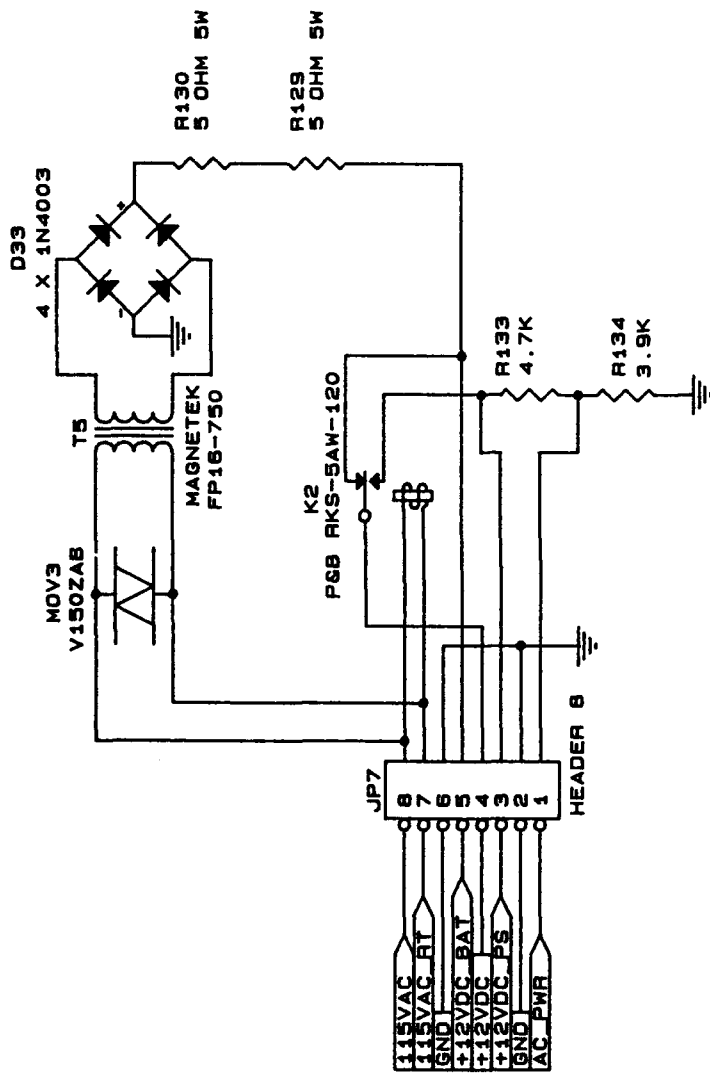
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Title

POWER UNIT

Size Document Number A XRLM FIG. 4 REV

Date: April 8, 1992 Sheet of



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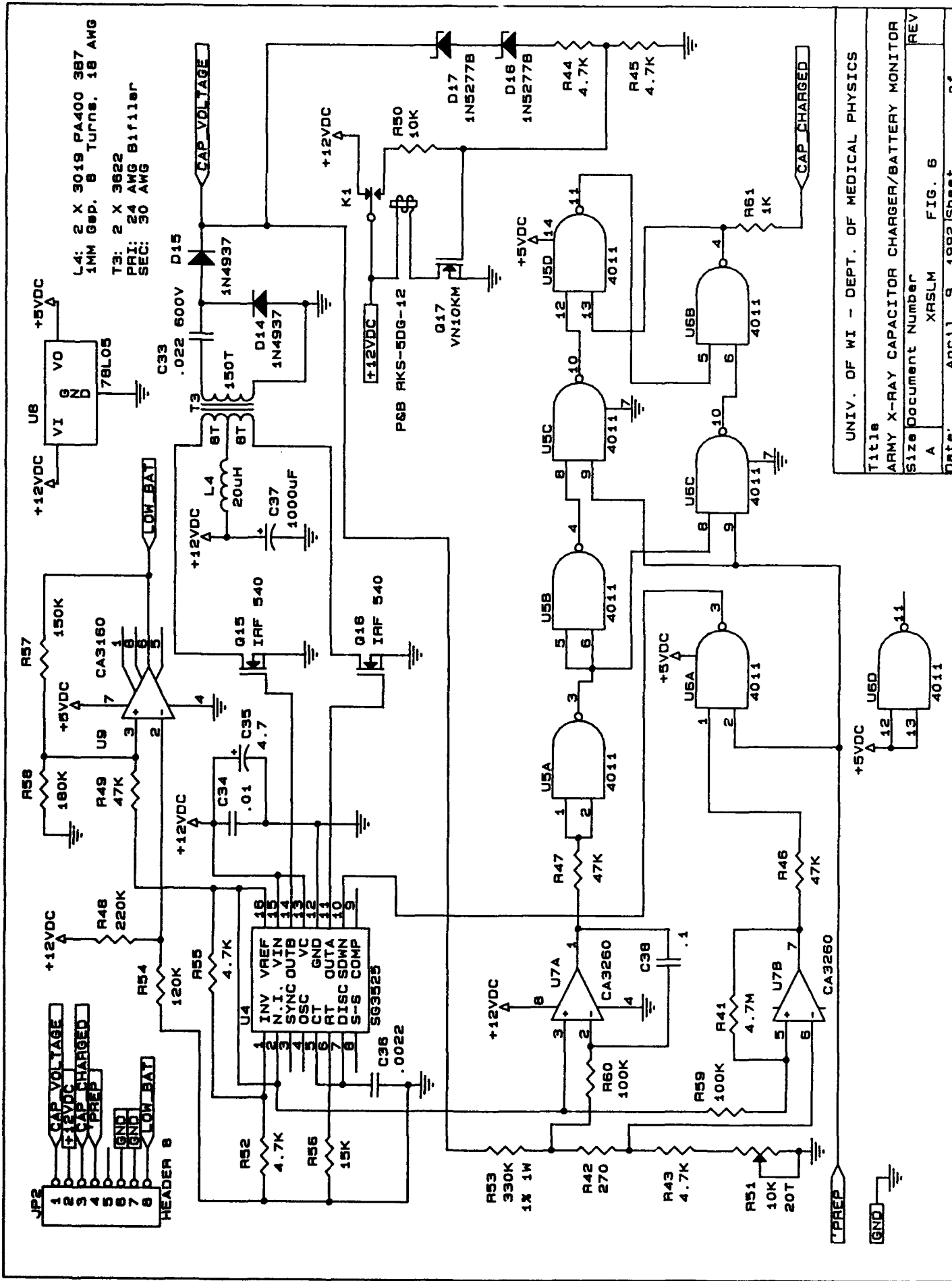
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ARMY X-RAY MACHINE BAT CHARGER/CAP DISCHARGE

Size Document Number

A XRSLM FIG. 5 REV

Date: April 9, 1992 Sheet 91



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Title	ARMY X-RAY CAPACITOR CHARGER/BATTERY MONITOR	
Size	Document Number	FIG. 6
REV	A	XRSLM
Date:	April 9, 1992	Sheet 01

power line. When connected to the power line with the power switch off, line voltage is applied to the primary of rectifier transformer T5 and to transfer relay K2. Power switch S1 applies line power to the +12 vdc power supply (mfr. Vicor, Andover, MA.).

## 2. Battery Charger and +12vdc Mains Supply

Transformer T5 feeds rectifiers D33. Their output is limited by resistors R129 and R130 and sent to the NiCd cells (battery) as a slow charging current. Charging takes place whenever the system is connected to the power line and the cells are designed for continuous charging. When the unit is not connected to the power line, relay K2 is not energized and the cells are connected to the lower section of the power switch S1. When the power switch S1 is energized and the system is connected to the power line, then the +12 vdc power supply is energized and connected to the system +12vdc mains via 15A circuit breaker CB1. When not connected to the power line, changeover to battery power is automatic via relay K2.

The +12 vdc mains is fed to a 5 volt regulator 78L05 U8 to provide +5vdc. The +12vdc mains is fed to a CA3160E opamp U9 connected as a comparator to verify that the +12vdc is actually above +10.0 vdc; if not, the output of the opamp goes high generating a "LOW BAT" signal which is fed to the control/display to prevent x-ray exposures.

## 3. Capacitor Circuits

Oscillator-driver SG3525 U4 feeds driving signals to power FET's Q15 and Q16. These feed the primary of transformer T3 which is connected to the voltage doubler of C33, D14 and D15 and sent to the capacitor bank of 4@ 0.02F/315 vdc. This circuit is a power inverter and receives its power from the contacts of K1. The capacitor voltage is also connected to the CA3260 dual opamp U7A and B via the voltage divider string of R53, R42, R43 and R51 potentiometer. U7B will change state at levels set by R51, typically +315 and +300 VDC at the capacitor. The positive feedback of the amplifier assures "snap" action as it feeds U6A NAND buffer and the shut-down control of the oscillator-driver U4. The effect of the circuit is to permit the capacitor inverter to charge the capacitor until the voltage is +315, the inverter is shut down until the voltage falls to +300 and then turned back on. This is a "bang-bang"

servo control (on/off control) of the capacitor voltage. The second input of NAND U6A turns off the capacitor inverter when the "PREP" signal is active to reduce the load on the +12 vdc mains during an actual x-ray exposure and the preparation phase when filament power is needed. The capacitor voltage is also fed to two 160 volt zener diodes D16 and D17. If the voltage of the capacitor bank rises above +320 volts, the FET amplifier VN10KM Q17 will conduct and energize K1 to disconnect the capacitor inverter from the +12 vdc mains. This protects the circuit from overcharging if the "bang-bang" servo fails.

The second half of the dual opamp U7A will change state when the capacitor voltage is more than 95% charged. The NAND gates of U5, U6B, and U6C, comprise circuit logic to indicate to the control display that the capacitor is charged and ready for an exposure; the complexity of the circuit prevents loss of the "CAP CHARGED" signal if the capacitor voltage falls during the exposure, i.e., in the presence of the "PREP" signal, as would be normal during an exposure.

#### 4. Safety Discharge Circuit

The capacitor bank is also connected to R1 1k 50W which is connected to the drain of an IRE740 power FET Q25. This FET has its gate connected to ground by the 4N26 optical coupler U20 if +12 vdc is present on the mains line. Under that condition, the FET appears as an open circuit and has no effect on the operation of the rest of the system. If +12 volts is not present on the mains and the capacitors are charged, then 470k resistor R128 clamped by zener diode D34 will apply a turn-on bias to the FET and the capacitor bank will discharge through R1 and Q25 with the greater part of the energy dissipated by R1. The maximum energy stored in the capacitor bank is 4 kJ, 4000 W-sec. R1 is rated at 50 W continuously and 250 W intermittently. The time constant of the circuit is 20 sec so that the rating of the resistor is not exceeded. However, it will get hot after only one discharge. The purpose of the safety discharge circuit is to discharge the capacitor bank when power is turned off or if there is a circuit failure. The stored energy of the capacitor bank can be lethal and must be treated with respect. Do not short circuit the capacitors with metal tools as there may be sufficient stored energy to vaporize the tool and damage the system. CAUTION: Even when partially charged, there can be enough energy stored in the capacitors to be dangerous. Always use a voltmeter to check for voltage and discharge the capacitors through a resistive load (1k, 50 W for one minute) to be safe.

## B. Control/Display

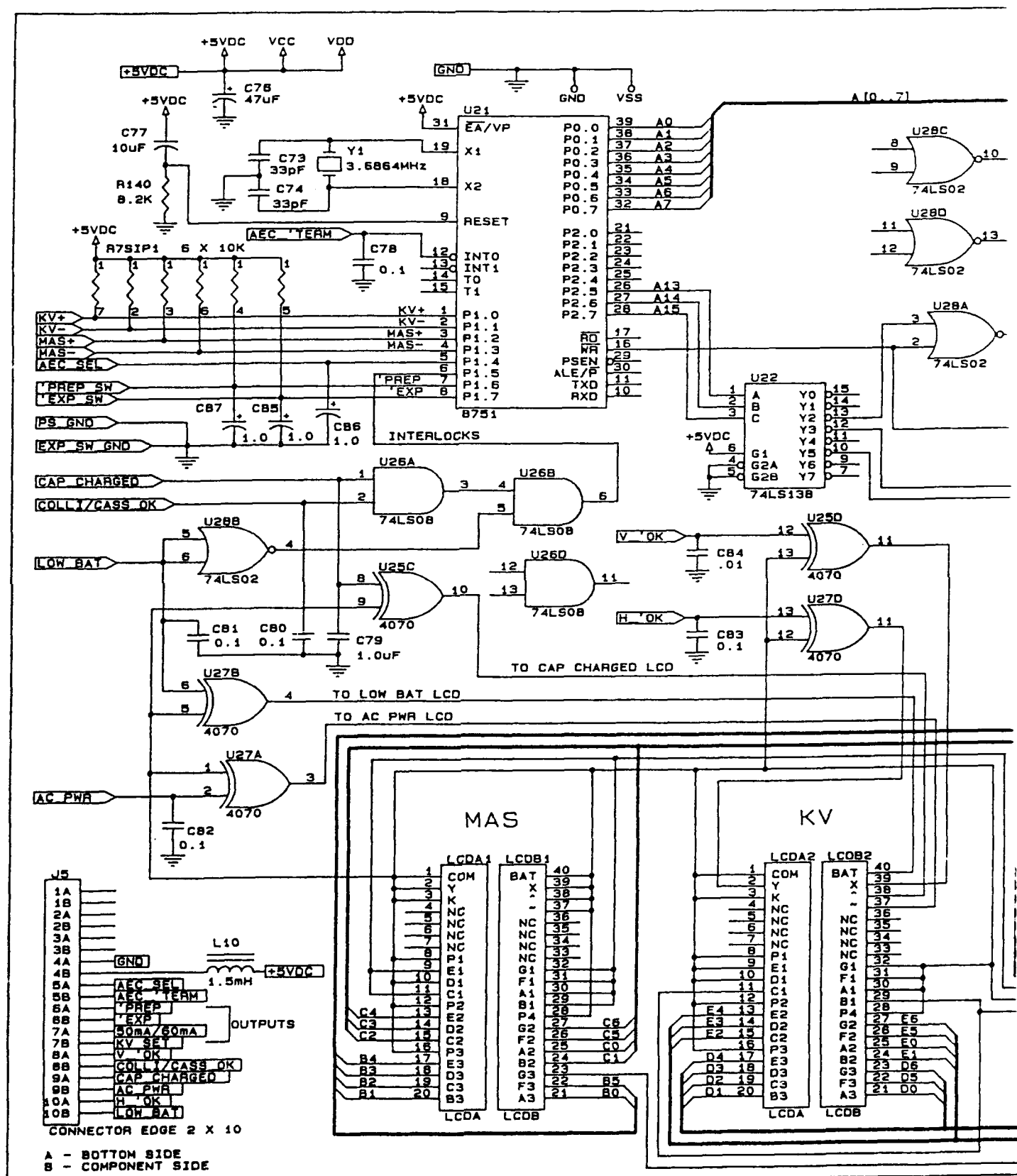
The Control/Display contains the microprocessor (uP), associated circuits, liquid crystal displays (LCD's), indicator lights, factor setting switches, and the exposure switch. The enclosure and switches are sealed against splashes of liquids and may be cleaned with mild disinfectants. It is designed to be hooked or attached to convenient mounting points on the system and the cable is sufficiently long so that the operator may initiate exposures from a safe distance. Fig. 7 is a schematic diagram of the uP System. Fig. 8 is a simplified diagram showing the input leads and each control and display element.

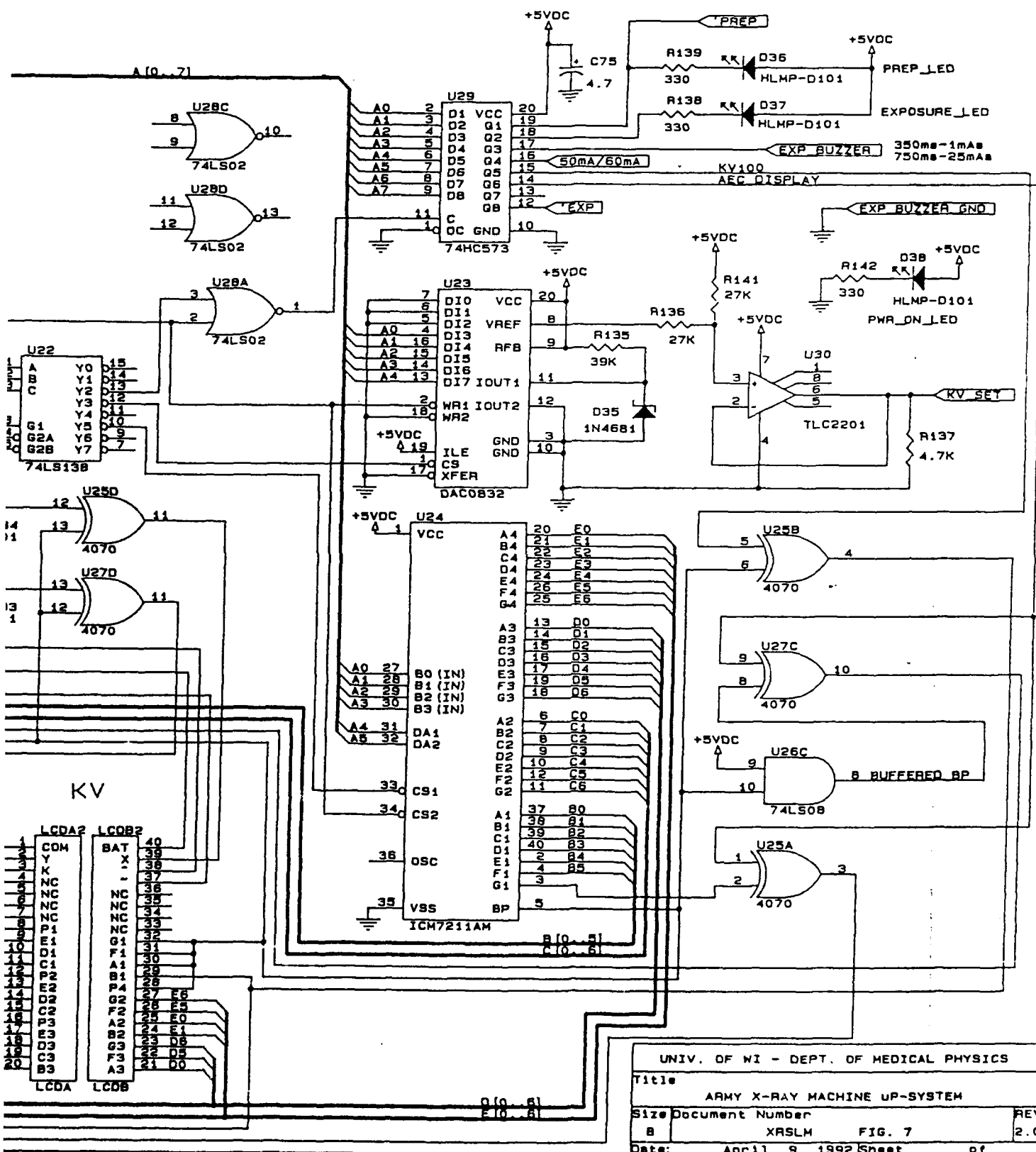
### 1. Microprocessor

The microprocessor U21 is an Intel 8751H which contains the program in internal ROM. Manufacturers reference manuals explain the operation and programming of this device. The microprocessor accepts the various logical control lines from the rest of the system and produces the various timing and control gates to operate the system, determine the exposure time, lock out operation when required and generate the signals for the displays. A program disc (separate from this report) contains the source code for the ROM. The ROM program on the uP has not been "protected" so that it may be copied.

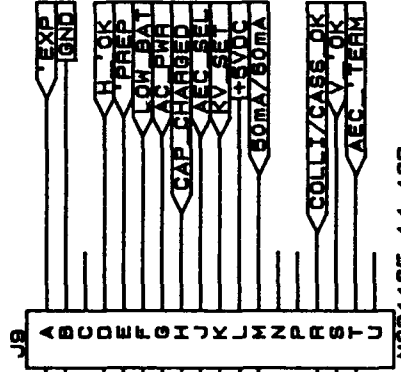
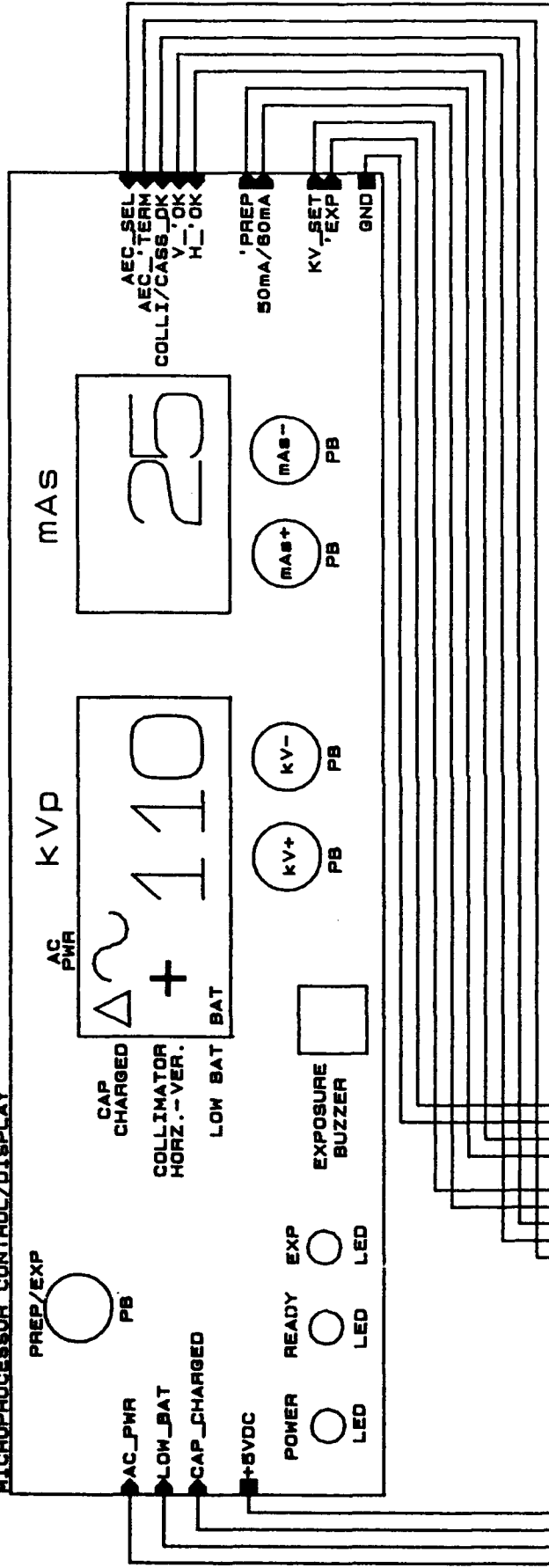
### 2. LCD's and Driver

Two 3-1/2 digit LCD's are driven by the digit driver ICM7211AM U24 and a quad exclusive OR gate 4070 U27. The driver receives its control signal from the uP and displays the kVp and mAs settings. When automatic exposure is selected at the cassette holder, the mAs display digits are changed to read "AEC". Logical signals originating from other circuits are also displayed as "BAT" for low battery voltage, a small sine wave indicating power line operation, a small horizontal bar indicating incorrect setting of the horizontal shutters of the collimator, a small vertical bar indicating incorrect setting of the vertical shutters (completing a "+" sign when both are incorrect), and a triangle indicating that the capacitor bank is charged. These signals are also fed to the uP preventing exposures if not correct. An octal latch 74HC573 U29 buffers signals used for the "prep" and "exposure" LED's, the exposure buzzer





# MICROPROCESSOR CONTROL/DISPLAY



MS3116F-14-18P

UNIV. OF WI - DEPT. OF MEDICAL PHYSICS		
Title		
MICROPROCESSOR CONTROL/DISPLAY ELECTRICAL		
Size	Document Number	REV
A	XRSLM	FIG. 8
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and the signal required for automatic changeover from 60 to 50 mA as kVp settings are increased.

### 3. kVp Control Voltage

The uP also feeds the digital/analog converter DAC0832 U23. This circuit converts the digital signal to an analog voltage proportional to the selected kVp. The voltage is buffered by the amplifier TLC2201 U30. That analog voltage is fed to the power switching regulator in the cross arm to set the anode voltage of the x-ray tube.

### 4. Exposure Switch

The exposure switch comprises a spring-loaded arm linked to two snap action switches. The arm lever lengths are unequal so that partial pressure actuates the first or "PREP" switch and full pressure actuates the second or "EXPOSURE" switch. The operation of the switch in two stages permits observation of the patient as the tube filament warms up (2.0 sec approx.) so that exposure can be made when the patient is ready; from 2 to several seconds after the first actuation. The "PREP" indicator will light after the filament delay and only if all interlock requirements have been satisfied. If the switch is depressed fully initially (without the two stages of finger pressure), the uP will time the circuit automatically and the exposure will occur about 2 seconds later.

## C. Cross Arm

The Cross Arm assembly contains the low voltage section of the x-ray tube anode supply. The energy stored in the capacitor bank of the Power Unit is fed to the switching regulator and converted to a constant voltage pulse which powers the main inverter. The circuit operates at very high efficiency, more than 80% of the capacitor energy fed to the circuit is applied to the x-ray tube. The inverter circuit feeds the transformer and voltage multiplier circuits in the tubehead to provide power to the x-ray tube. Current limiting and control circuits protect the circuit from the high transient currents caused by the initial charging of the high voltage capacitors in the voltage multiplier. They also help prevent the circuit from being damaged by arcing, a normal failure mode of an x-ray tube. X-ray tubes can develop residual gas and may arc as the tube warms up. After a short warm-up, particularly if the tube has not been used for several weeks, the tube will

clear itself and operate properly. A filament control regulator and power supplies complete the electrical system. The inverter requires a floating power supply and a negative voltage supply is required by the switching regulator as a turn-off bias for the switching transistor. The Cross Arm is also the support structure for the tubehead, cassette holder and mounting bearing assembly. Figs. 9 to 13 are schematic diagrams of the internal circuit boards of the Cross Arm.

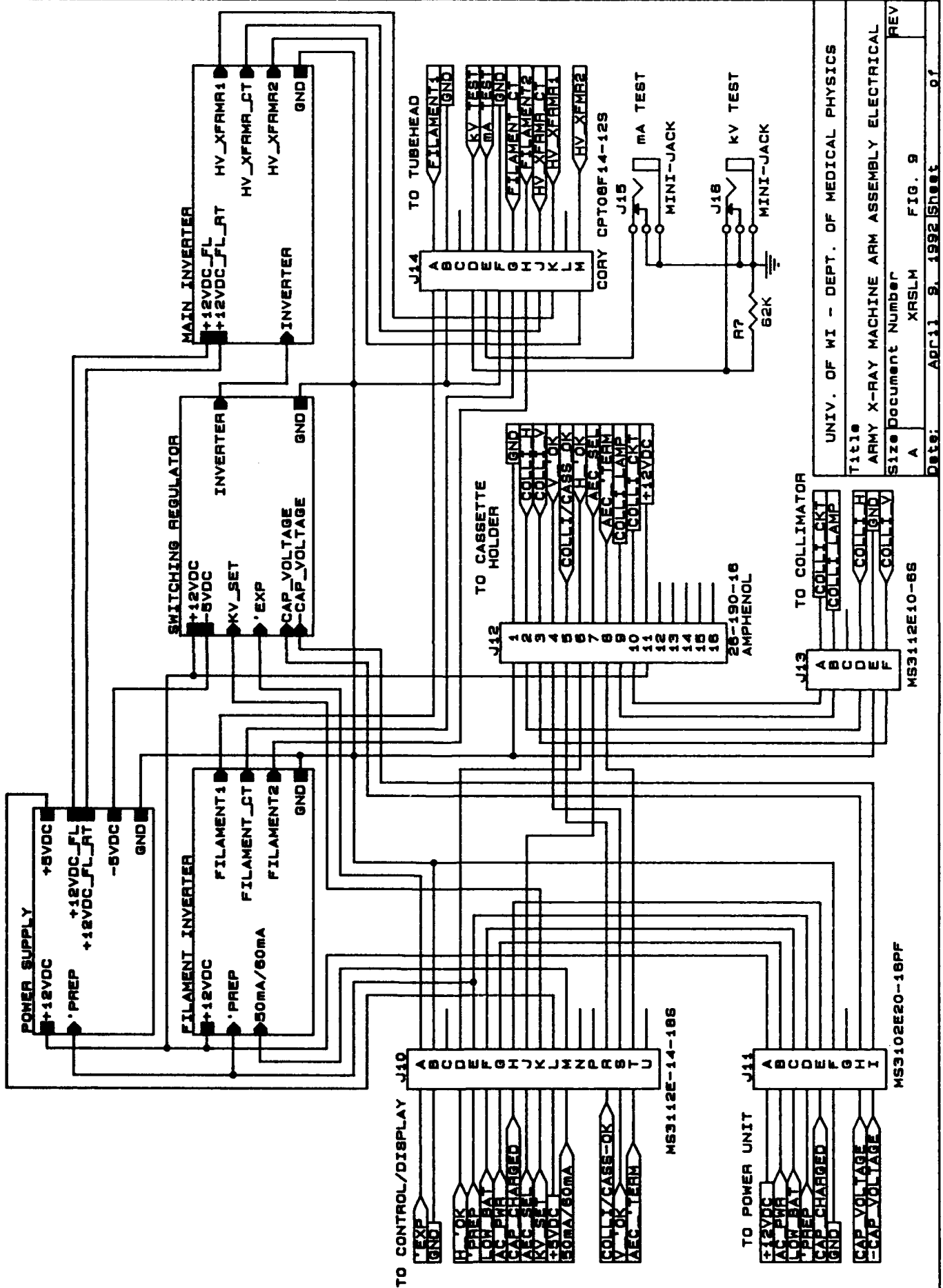
A practical note: the power signal levels are quite high, up to 10 kWp, and the power frequencies are of the order of 35 kHz. Stray interference and ground loops caused by the coupling effects of wiring and circuits close to each other can affect circuit operation. It is essential that all circuits are connected properly and with extremely tight connections. The metal structures are an important part of the circuit. The system may not function without damage if certain circuit boards do not have firm mechanical connection to the metal structures.

## 1. Power Supply

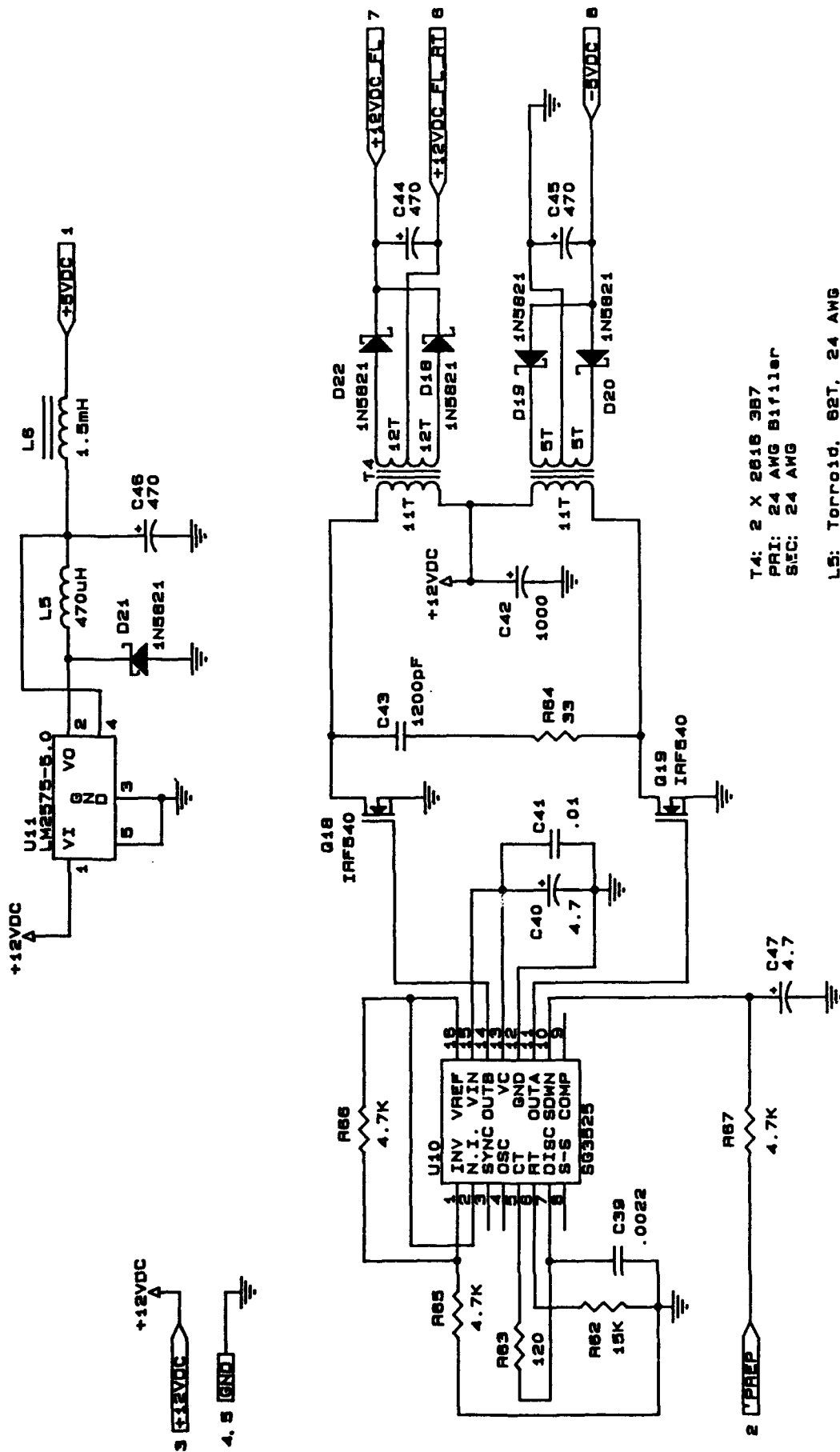
This circuit is similar to the capacitor charger in the Power Unit in that an oscillator-driver SG3525 U10 feeds a pair of power FET's IRF540 Q18, Q19, which power a small transformer. Two secondary windings provide power to four high frequency diodes D18-22. Because the circuit operates at close to 25 kHz, output filtration is minimal, single 470 uF capacitors C44, C45 are sufficient. The driver circuit is energized by the presense of the "PREP" signal to conserve battery power. An integrated circuit switching regulator LM2575-5.0 U11 provides +5 vdc from the +12 vdc mains with minimum loss. This circuit powers the uP.

## 2. Switching Regulator

The circuit is essentially a scaled-up version of switching regulators used in many computers. The voltage of a capacitor decreases during discharge and the concept here is to convert the varying voltage of the capacitor bank to a fixed voltage pulse with minimum loss. The simplified circuit of Fig. 14 helps to understand the the concept as it shows the equivalent circuit and compares it to a computer power supply. In the computer power supply circuit, the capacitor is fed to the switching transistor, then to the series inductor and clamp diode and then to the load. As the switching transistor is turned on, current rises in the inductor and to the load. When the switch-

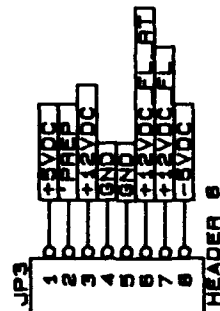


UNIV. OF WI - DEPT. OF MEDICAL PHYSICS	
Title	
ARMY X-RAY MACHINE ARM ASSEMBLY ELECTRICAL	
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A	XRSLM
REV	FIG. 9
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Sheet	01

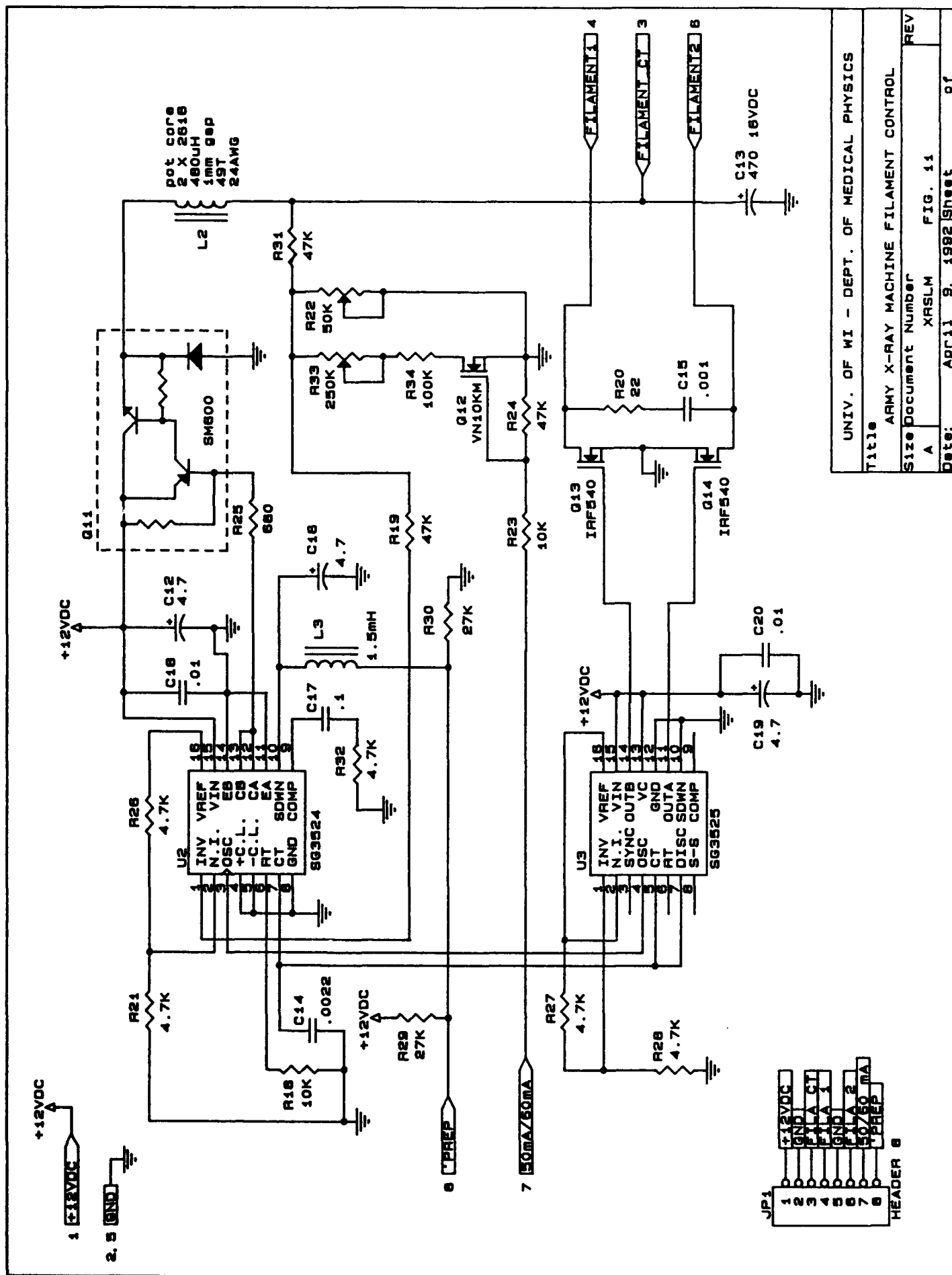


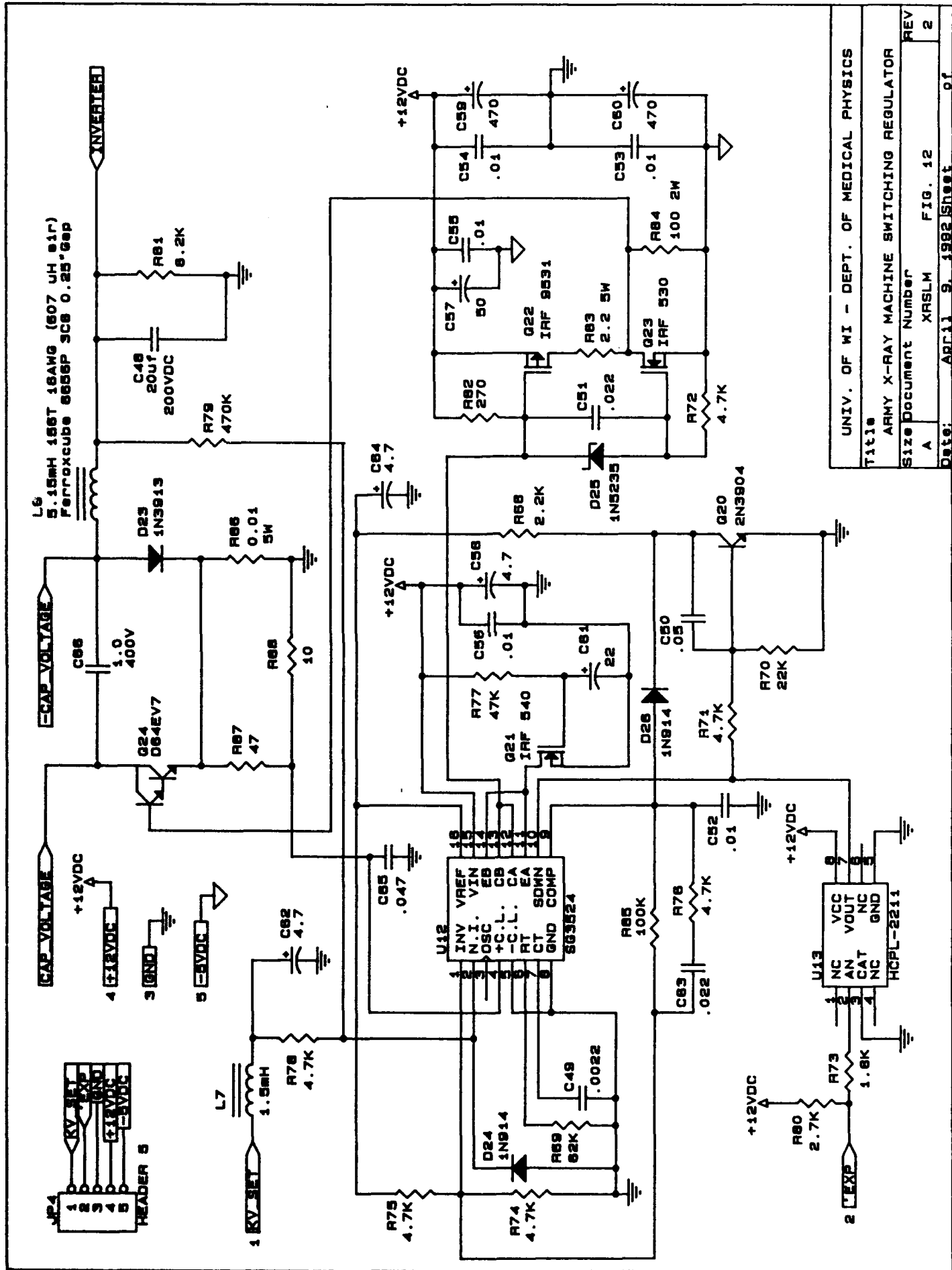
T4: 2 X 2018 3B7  
 PRI: 24 AWG B111er  
 SEC: 24 AWG

L5: Torroid, 62T, 24 AWG

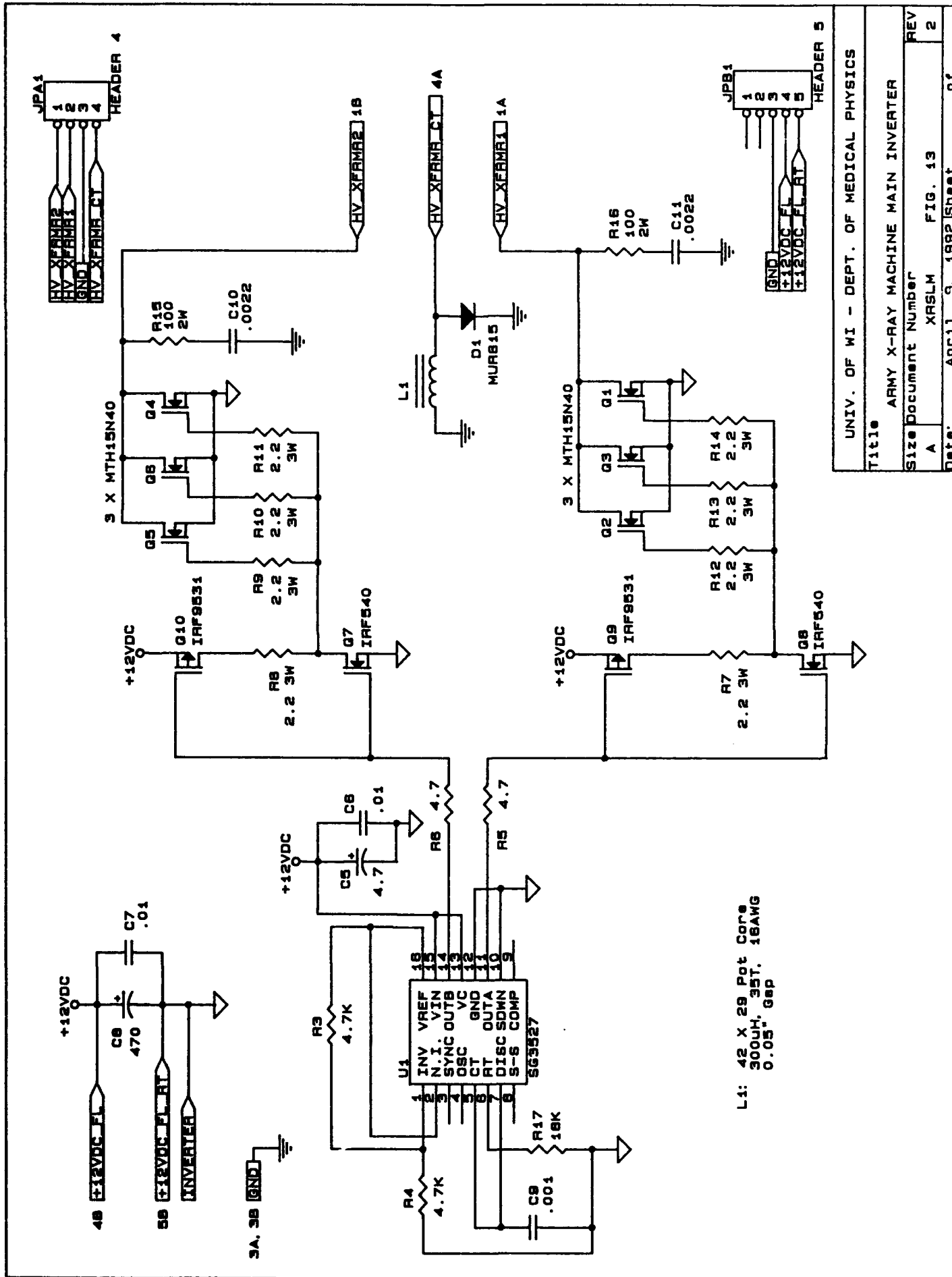


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Title	ARMY X-RAY MACHINE POWER SUPPLY	
Size	Document Number	REV
A	XRSLM	FIG. 10
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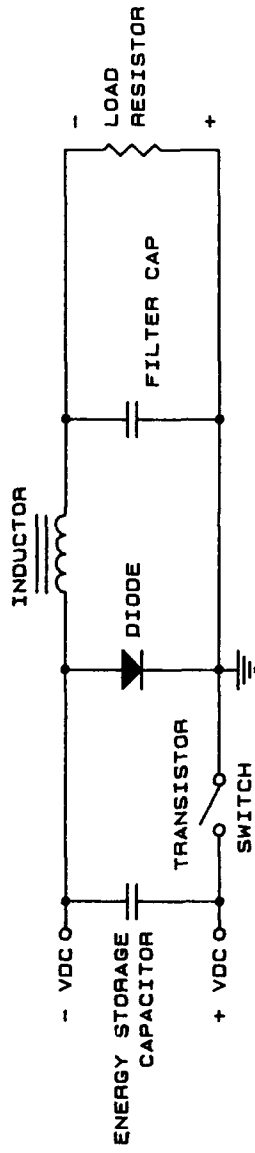




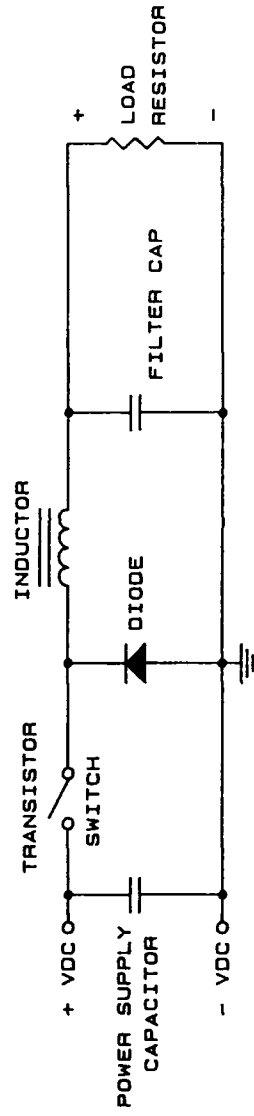
UNIV. OF WI - DEPT. OF MEDICAL PHYSICS	
Title	
ARMY X-RAY MACHINE SWITCHING REGULATOR	
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A	XRSLM
REV	FIG. 12
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ARMY X-RAY MACHINE MAIN INVERTER		
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XRSLM EQUIVALENT SWITCHING REGULATOR



COMPUTER EQUIVALENT SWITCHING REGULATOR

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Title

SIMPLIFIED SWITCHING REGULATOR COMPARISON

Size	Document Number	FIG. 14	REV
A	XRSLM		

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ing transistor is turned off, the energy stored in the inductor causes the voltage at the input to the inductor to fall rapidly toward ground potential where it is clamped by the diode. The current through the inductor to the load begins to fall and the switching transistor is turned on again for another switching cycle. The voltage to the load is controlled by the duty cycle of the switch and diode circuit, i.e., the fraction of on and off times. Operation is at high frequencies, around 10 to 100 kHz, limited by the storage characteristics of the diodes and other circuit elements. The switching regulator of the XRSLM operates close to 10 kHz. The circuit of the XRSLM is similar to the computer power supply but the order of the components is changed to generate a powerful pulse of negative polarity and also permits the switching control circuits to operate near ground potential, an important consideration at these power levels.

The oscillator-driver SG3524 U12 is arranged as a single driver feeding a bidirectional buffer (totem pole) of Q22 and Q23. This circuit is capable of providing drive currents of almost 5 amp to the base of the the switching transistor D64EV7 Q24. This transistor is capable of very high pulse currents of up to 100 amp. This high drive capability is necessary to assure saturation during conduction and rapid turn-off for each switching cycle. Power FET IRF540 Q21 in the output drive return lines of the SG3524 prevents accidental operation during power-up cycles of the system and has no effect on normal operation. The "EXP" signal is fed through the optical coupler HCPL-2211 U13 to the shutdown terminal of the SG3524 to disable the driver in the absence of this signal. That signal is also fed to the clamp transistor 2N3904 Q20 to clamp the internal opamp output of the SG3524 to assure a "soft-start" of the power pulse. The optical coupler is used to isolate the uP from stray interference which could be caused by the high frequency switching transients.

During the exposure, the output pulse appears at the "INVERTER" terminal and is also fed through a 470k resistor R79 to the comparison point, pin 2 of the SG3524. The "kV SET" voltage from the uP is filtered by L7 and C62 and fed to the comparison point through the 4.7 k resistor R78. The internal 5v reference of the SG3524 is divided by R74, R75 to provide the 2.5 v reference for comparison. Depending on the voltage from the uP, the power pulse will range from -75 to -135 vpeak, corresponding to 60 to 110 kVp at the anode of the x-ray tube.

The return path of the power pulse to ground potential is through the viewing resistor 0.01 ohm R86. A pulse current of 50 A will produce a voltage drop of 0.5 volts,

reduced to about 0.08 volts by the divider of R87 and R88. This voltage is fed to the current limiter control terminal of the SG3524. Current limiting occurs when the voltage input exceeds about 0.2 volt so that abnormally high pulse currents will cause the duty cycle of the switching circuit to reduce output power to safe limits. During the early phase of the x-ray exposure, the internal capacitors of the tubehead require high charging currents and this current limiter keeps the circuit to within safe limits.

### 3. Inverter

The inverter accepts the negative power pulse and converts it to a square wave single phase power at approximately 35 kHz. The SG3527 U1 oscillator-driver feeds a pair of bidirectional buffers Q7-Q9 which provide low impedance drive signals to the power FET's Q1-Q6. These power FET's are connected in two assemblies of three FET's each. The drains of the power FET's are led to the primary of the high voltage transformer in the tubehead. The center tap of the transformer is returned to ground potential via inductor L1 and clamp diode MUR815 D1. Switching transients and the transformer secondary distributed capacitance can result in very high current pulses of short duration which are capable of damaging the system. The inductor limits the rate of change of current and the diode clamps the voltage spikes with minimum circuit losses. To conserve system energy the circuit drive is enabled only when +12 vdc is applied from the power supply board, which occurs when "PREP" is active. Therefore, the circuit produces output energy only when the power pulse is applied.

### 4. Filament Control

The filament transformer is contained within the tubehead. A small ferrite cruciform core operates at about 30 kHz and has a conventional wound primary with the secondary comprising three turns of high voltage insulated wire. The control circuit consists of a switching regulator feeding a saturated inverter. The switching regulator comprises the SG3524 U2 feeding the pass transistor/diode 5M600 Q11. Energy is stored in inductor L2. The output voltage is set by the feedback resistors R19 and R31 shunted by R22 and R33/R34 in series with FET VN10KM Q12. When Q12 is off, the output voltage of the regulator circuit is set by R22 to set the x-ray tube anode current to 50 mA. To increase the tube anode current to 60 mA, Q12 is turned on by the uP and the additional load of R33 and R34 increases the output voltage. R33 is a

potentiometer that sets the 60mA current. It is important that R22 is adjusted first, then R33. The switching regulator is turned on by the uP "PREP" signal. The switching regulator output voltage is fed to the saturated inverter circuit of SG3525 U3 and the two power FET's Q13, Q14. Because the filament load is almost a perfect resistance, no special measures are needed to filter the primary center tap of the filament transformer. Potentiometers R22 (50 mA) and R33 (60 mA) are used to set the filament power levels. The uP causes the current level to switch automatically at 84 kVp from 60 to 50 mA to stay within the ratings of the x-ray tube.

#### D. Tubehead Circuit

The tubehead contains the high voltage circuits and the x-ray tube. The circuit comprises a pair of voltage sextuplers which multiply the voltage of the high voltage transformer secondary by a factor of twelve to produce up to 110 kVp to the anode of the x-ray tube. Actually, +55 kVp is produced at the anode and -55 kVp at the cathode. Voltage and current monitoring circuits are also provided. Fig. 15 is the schematic diagram of the Tubehead circuit.

**CAUTION:** The high voltage circuits must be operated in oil after vacuum processing to eliminate bubbles. Failure to vacuum process will cause the circuits to arc and be damaged. Potentially lethal voltages are present within the tubehead during operation.

##### 1. Voltage Multiplier

The transformer secondary feeds the voltage multiplier board. Each voltage sextupler consists of three stacked voltage doublers with decreasing numbers of parallel capacitors; 5@ 4000 pF (lower section), 3@ 4000 pF (mid section) and 1@ 4000 pF (top section). Note that the lower section carries the current of the two higher sections requiring the higher value of capacitance.

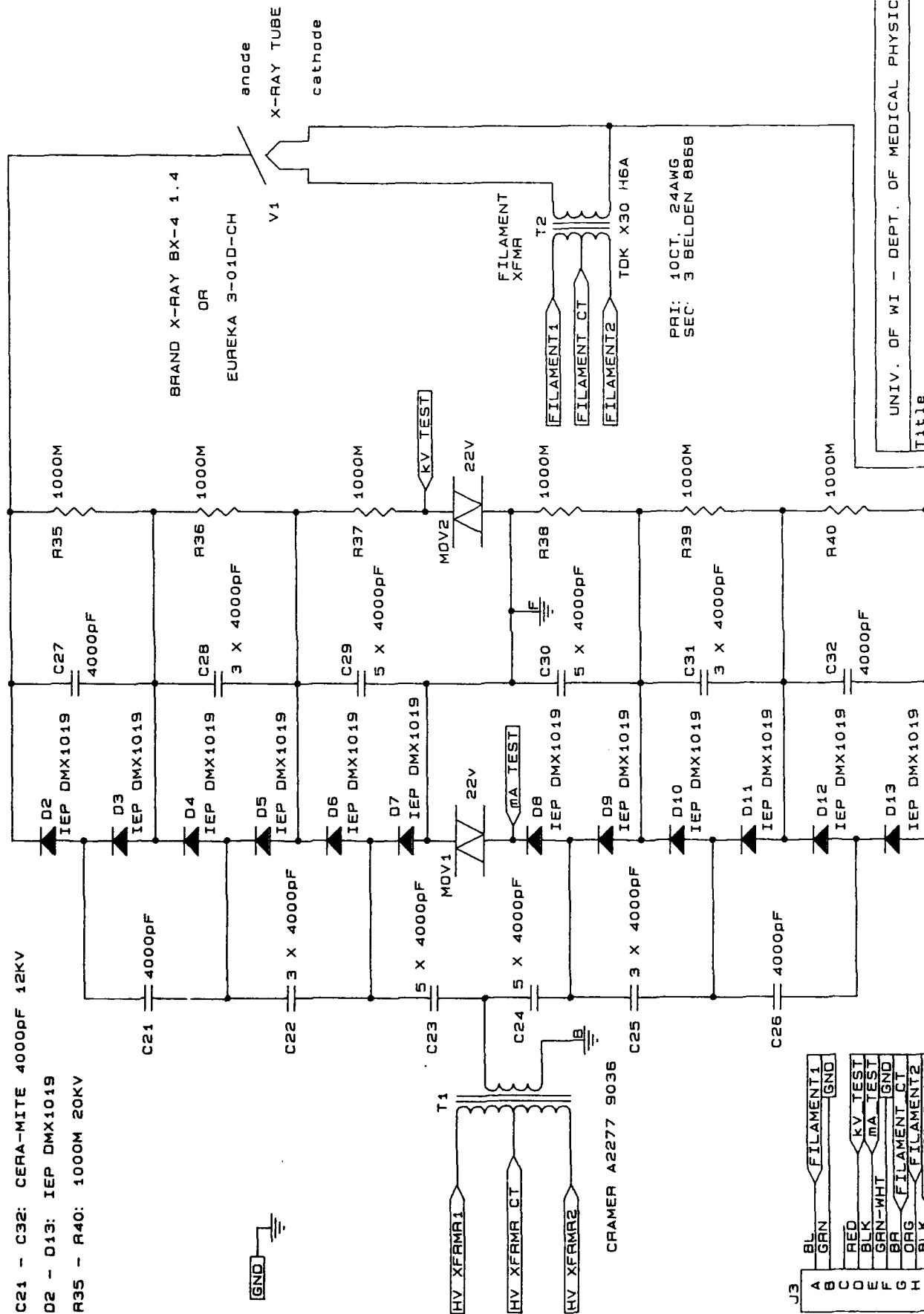
##### 2. Voltage/Current Monitoring

The rectifier diodes are arranged in series with the cathode string and returned to ground through the mA test circuit line. In the event of an external open circuit, the metal oxide varistor will conduct if the voltage exceeds 22 v. A conventional mAs meter may be used to read tube current with no correction factor. Each of the voltage

C21 - C32: CERA-MITE 4000pF 12KV

D2 - D13: IEP DMX1019

R35 - R40: 1000M 20KV



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Title

ARMY X-RAY MACHINE TUBEHEAD CIRCUITS

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A XRSLM FIG. 15

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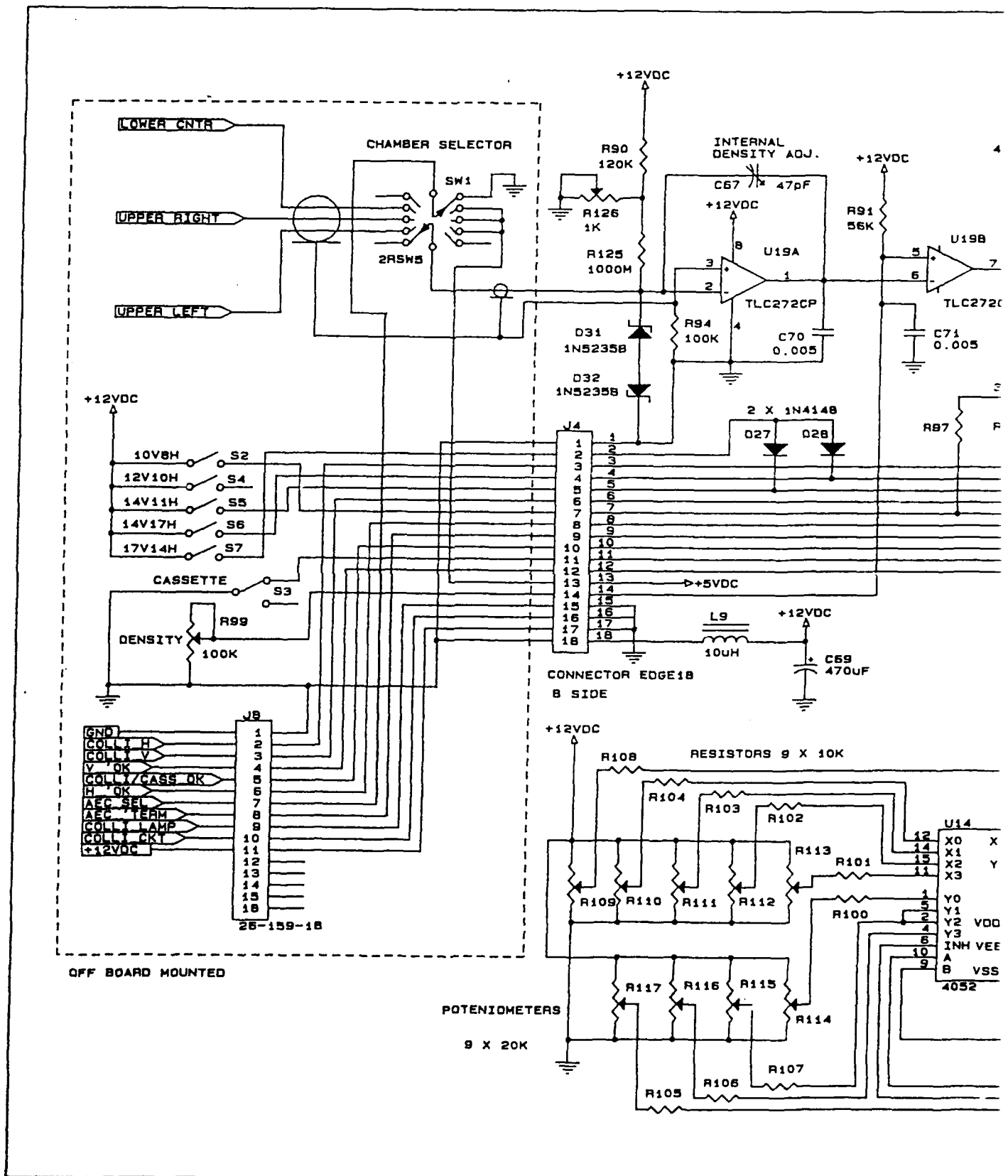
doubler stages is by-passed by a 1000 M resistor. The lower section doubler resistor on the anode side is returned to a voltage monitoring line and protected with a 22 v metal oxide varistor. Because the series resistance is 1000M and the circuit is a twelve times multiplier, the voltage measurement point should be terminated in a 60 k resistor for a calibration factor of 1.0 volt/100 kVp. Direct-reading x-ray voltage calibration devices which use paired sensors with energy filters may also be used to measure effective kVp by monitoring the x-ray beam itself.

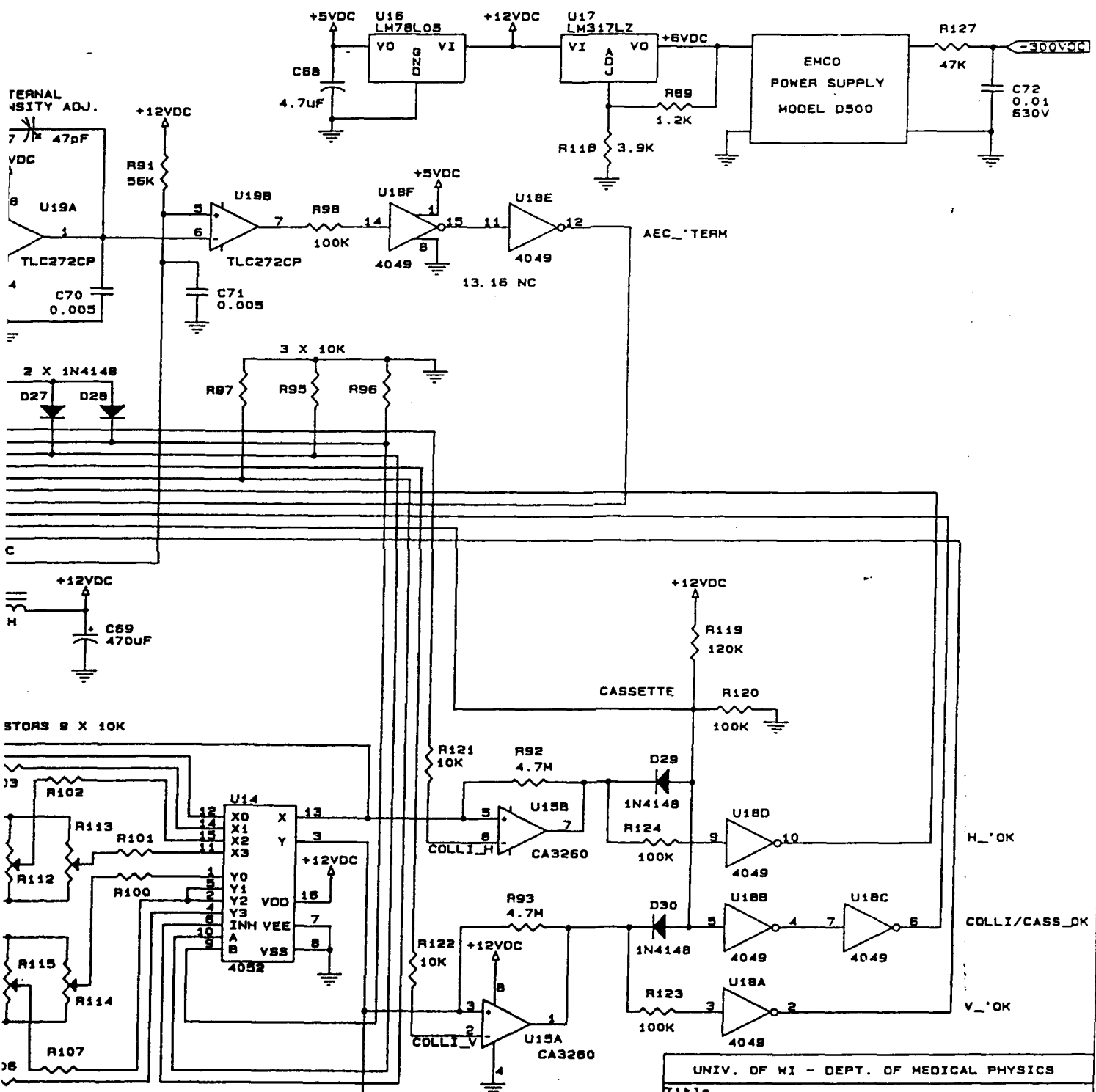
#### E. Cassette Holder Circuits

The Cassette Holder contains the circuits for the automatic exposure control, cassette size and presence logic and the control and selector switches and the density control for the automatic exposure control. Power supply regulators and the high voltage power supply for the ion chamber are also on the circuit board. The entire assembly is connected to the Cross Arm by a ribbon type rack and panel connector. Fig. 16 is the schematic diagram of the Cassette Holder circuits.

##### 1. Cassette Size Logic

A series of small switches, S2 and S4-S7, sense the position of the mechanism which sets the machine for the various cassette sizes and position. Switch S4 is not connected. These switches are used as address lines to a 4062 dual four channel multiplexer U14. This circuit selects combinations of the voltages selected at potentiometers R109-R117 for comparison with voltages selected at the collimator by the dual opamp CA3260 U15A and U15B. When the voltages at the potentiometers are less than the corresponding voltage from the collimator, corresponding to x-ray field sizes equal or less than the dimensions of the selected film in the cassette, then the output of each comparator is positive. A small positive feedback (note the 4.7 M feedback resistors R92, R93) assures "snap-action" by adding a slight hysteresis to the response of the comparators. When both comparators are positive and if switch S3 is open (cassette in place), then the logic circuit of U18B and U18C feeds a positive signal, "COLLI/CASSETTE OK" to the uP. Each comparator also feeds a logic circuit U18A and U18B to provide negative (0) signals for the vertical and horizontal shutter settings of the collimator, "V'OK", "H'OK", to the uP.





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Title ARMY X-RAY MACHINE AEC/CASSETTE READY			
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B	XRSLM	FIG. 18	
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## 2. Automatic Exposure Control Circuits

The ion chamber is excited with a bias provided by the Emco power supply. This is powered by the 9 volt regulator LM317LZ U17 to produce -350 vdc, filtered by the RC of R127 and C72 and fed to the cathode of the ion chamber. The ion chamber is divided into three segments corresponding to right and left lung fields and spine. A segment is selected by switch SW1 and fed to the electrometer (low leakage opamp) TLC272CP U19A. This is a dual opamp with the first section arranged as an integrator and biased low by 1000M resistor R125. This very high value resistor is returned to the junction of R90 and potentiometer R126. The potentiometer is set just below that point where the output of the integrator returns to zero in about 3 sec after an exposure. The very small currents involved require that special care must be taken to insulate and shield the input leads to the opamp (pin 2). The operation of the circuit is simple: ionization currents are produced in proportion to the radiation intensity reaching the cassette through the patient, this current is integrated and the output voltage crosses a threshold at the comparator of U19B, output logic terminates the exposure when sufficient radiation has reached the cassette. The setting of the integrating capacitor C47 determines the gross sensitivity of the circuit, i.e., the point where the exposure is terminated. Fine sensitivity (over a 2 to 1 ratio) is set by the density control potentiometer R99. Logic amplifiers U18E and U18F buffer the terminate signal and feed negative logic to the uP as "AEC 'TERM'". The switch SW1 is used to select the segments of the ion chamber and can be rotated to the off position for normal timing of the x-ray exposures. When the automatic exposure control is used, a signal fed from the switch to the uP causes the time display to show "AEC" and sets the exposure time to maximum, corresponding to 20 or 25 mAs (25 or 30 mAs when larger energy storage capacitors are used). In the event that the circuit fails to terminate the exposure, "AEC" will flash on and off and require that the operator reset the control display circuit by pressing the mAs 'down' button. This is a practical indication that the circuit failed for any reason.

## 3. Ion Chamber

The ion chamber for the automatic exposure control consists of an aluminum frame supporting two sheets of aluminized polycarbonate. The aluminum outer surface of the sheets serves as an electrostatic shield for the extremely small ion current signals. The common cathode element is painted on the inner surface of one sheet

with conducting graphite (Aquadag-R) and connected to the -350 vdc power supply. The anode sheet has the three segments or fields painted with graphite and conducting leads painted to the point of connection to switch SW1. The distance between the sheets is 1.2 cm and the area of each segment is close to 100 square cm, and volume of 120 cubic cm. No provision is made for x-ray energy compensation. The ion chamber and the automatic exposure circuit are intended for use in chest radiography and not for general application.

## F. Collimator Circuits

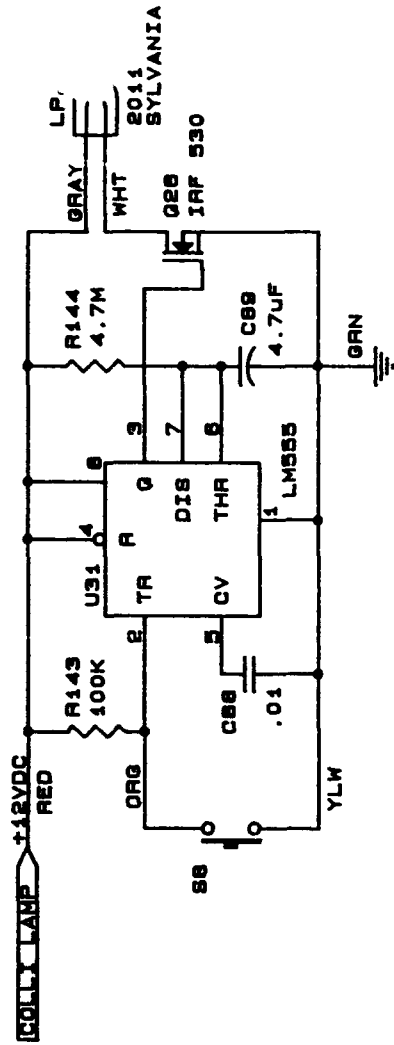
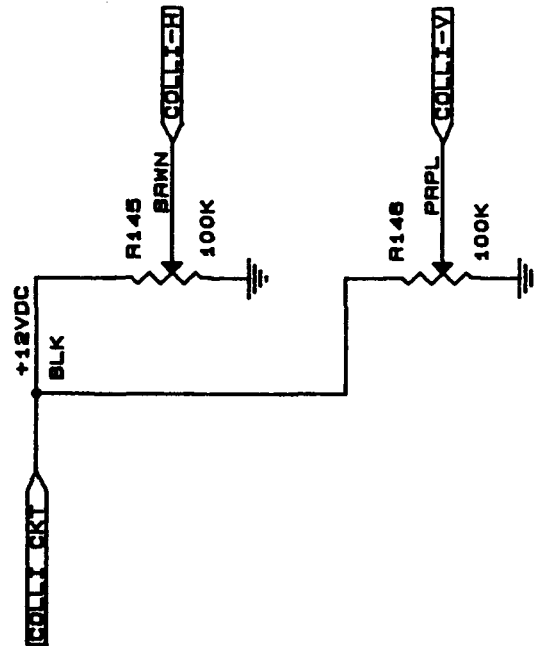
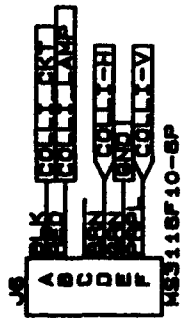
The collimator is a small commercial collimator modified for this application. While commercial collimators are available which are rated to 125 kVp, they are relatively large and heavy, and would have to be modified and tested for use with fixed anode x-ray tubes. The smaller device as received was shielded for 80 kVp and was modified to add lead foil shielding, change the quartz halogen lamp to one of lower power, add a lamp timer to turn off the lamp after 30 sec and add potentiometers to sense field size. Because this commercial collimator has been modified, it became a new product and it will be necessary to test it for radiation performance and shielding and submit a new product report to CDRH/FDA with test results. The schematic diagram of the Collimator circuits is shown in Fig. 17.

### 1. Aperture Sensing

Two 100k potentiometers were mounted in the collimator. Matching nylon gears couple the potentiometers to the mechanism for setting the aperture shutters. The potentiometers are positioned so that minimum voltage is produced at the arm of each potentiometer when the aperture is set to a minimum.

### 2. Lamp Timer

The original quartz iodine lamp provided with the collimator was rated 12 V/50 W. This high brightness lamp was necessary as the collimator was intended for use at larger focus-film distances than the 100 cm of the XRSLM. To conserve battery power, the lamp was changed to 12 V/15 W. To keep the lamp from remaining on after the operator adjusts field size, a 30 sec. timer is used. The timer uses an LM555 U31 relaxation circuit biased on. Pressing the switch causes the timing capacitor to



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ARMY X-RAY MACHINE COLLIMATOR/TIMER		
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discharge and a positive signal (almost +12 v) to appear at the Q output (pin 3) during the time the capacitor recharges. When the voltage of the capacitor increases above the internal bias point of the LM555 (about +8 v), the Q signal toggles to zero. A positive signal at Q turns on the power FET Q26 which will turn on the lamp.

## VI. Testing

Each of the basic assemblies should be tested before their interconnection. The NiCd battery should be charged before use. The self-discharge rate of the battery is between 5 - 15%/week. Simple test procedures can be used for the separate tests. For field use, as part of a program for maintenance and repair, special tools can be devised to simplify the testing. In the laboratory, standard instruments, power resistors and other common components can be used. The tests described in the following sections are basic tests of performance which may be used to isolate problems. They are not complete tests of performance or calibrations which must measure operation under every condition, e.g., exposure times, battery voltage, etc. They are general tests which cover most of the common problems and simple calibrations. Field instruments could be patterned after these laboratory tests.

**DANGER!** Be aware of high voltage present in many circuits. The energy stored in the capacitor bank is capable of destroying tools and is potentially lethal. The battery is capable of short circuit currents greater than 50 amps. The very high currents of the switching regulator and power inverter require firm grounding of the circuit boards and loads.

### A. Power Unit

With the Power Unit disconnected from the Cross Arm, connect a voltmeter (1000 vdc scale) across pins H and I of J2. Jumper pins I and F of J2. Connect the unit to a normal 115 vac power line, with the power switch S1 off. The neon pilot lamp LP1 should light. Turn on the the switch S1 and the capacitor voltage should rise to +300 to +315 vdc in 90 to 120 sec. Turn off the switch S1 and observe that the capacitor bank voltage should fall slowly to less than 25 vdc in 5 minutes.

Connect a 12 volt headlamp bulb or a power resistor (5 ohm 50 W) between pins A and F of J2. Connect the unit to a normal 115 vac power line and turn on the power switch S1. The bulb should light and the voltage across the bulb should be +11.5 to +12.5 vdc. Disconnect the power line during the test and the voltage should remain between +11.0 and +12.5 vdc. If possible, leave the system disconnected from the power line and let the batteries discharge to below +10.5 vdc and note that the voltage on pin C will switch from 0 to +8 to +10.5 vdc as the battery voltage decreases, but stays near 0 v for a charged battery. Connect to a normal power line with the power switch S1 off and allow to charge for 14 hours after the battery has discharged.

## B. Control/Display

A simple test fixture is required in addition to a +5 vdc power supply and common meters and oscilloscopes. The test fixture comprises an MS3112F-14-18P connector wired as follows: pins A, E, M to 10 mA LED's (common red LED through 390 ohm resistors, LED cathodes to ground), pins D, F, G, H, J, R, S, T connected to SPDT toggle switches (between ground and +5 vdc), pin L to the +5 vdc power supply, pin B to the power supply and test ground. Switches are off when set to ground. Exposure time is measured at pin A.

With all switches except T turned off, connect to the +5 vdc power supply. The LCD's should indicate 60 kVp, 1 mAs, the collimator "+" sign should not be displayed. The up/down buttons should cause the display to vary kVp and mAs. Operation of switches D and S should display the horizontal and vertical parts of the "+" sign. Operation of switch J should cause the mAs display to change to "AEC". Operation of Switch H should light the triangle symbol, simulating the indication for a charged capacitor bank. Operation of switch G should cause the sine wave indicator of AC power to be displayed.

With all switches except T turned off and the circuit powered, press the exposure switch; test indicators A and E should remain on and M should be off, nothing should happen when the exposure switch is pressed. Turn on switches H and R and press the exposure switch part way, the READY LED and indicator E should light. Press the exposure switch the rest of the way and the EXPOSURE LED and indicator A should now light. Exposure time may be measured with an oscilloscope at indicator A. Note that indicator A is a very short flash while the EXPOSURE LED is "stretched" to make it easier to see. The exposure buzzer will also sound. If either or both switches G and R are turned off, the system should not indicate either READY or EXPOSURE. When set for kVp levels of 82 and below, the indicator M should light. Turning off switch T before an exposure should cause the display LCD's to flash on and off until reset.

## C. Dummy Load Testing

The Power Unit, Control/Display and the Cross Arm are connected and the tubehead, collimator and cassette assembly are not connected. A connector and test fixture are used to simulate the tube head. The test fixture comprises a dummy load transformer (see VII.

B.), a dummy load resistor of 10 ohms, 200 W non-inductive (Globar or equivalent), a filament transformer with a 12v, 12 W pilot lamp. The components are wired in the same relative positions as the actual tubehead components.

The system is normally interlocked by settings of the collimator and the cassette holder so that an exposure cannot be made without a cassette in place, or with the collimator field size larger than the selected film size. In order to make test exposures, certain pins of the cassette holder connector have to be jumpered to simulate correct operation and defeat these interlocks. Either a mating connector with jumpers or test leads with alligator clips may be used as follows: Cassette Holder connector J8 (connect a 4.7k resistor between pin 11 and pin 5, connect a 3.9k resistor between pin 5 and pin 1, connect pin 7 and pin 1.

With the test fixture connected, the system may be turned on and set to the shortest exposure and lowest kVp. Make test exposures and observe the dummy load AC P-P voltage levels as the kVp settings are varied. These levels should range from 250 to 500 v P-P. Danger! These voltages are potentially lethal. The pilot light simulating the filament should be moderately bright, less bright when set at 84 kVp or above. The bulb should be off until the READY light is lit.

#### D. Simple X-Ray Tests

The system must be fully assembled with the cassette holder, tubehead and collimator in place. An empty cassette should be used. Exposure tests can be done by the use of either the internal provisions for testing with mA and kV meters or by external sensors which measure the x-ray output and then calculate the system factors. Two mini-jacks on the Cross Arm are the terminations of resistive dividers or rectifier output in the tubehead. The mA jack must be terminated in a suitable mAs meter such as the Nuclear Associates Model 07-472. This will read actual mAs for each exposure. Because of the charge accepted by the voltage multiplier capacitors, an error of up to 1 mAs may be normal. The kVp is read from the resistive divider as 1.0v/100 kVp using a storage oscilloscope having an input impedance of 10 megohms. Using an oscilloscope of 1 megohm input impedance will result in an error of about 5% (reads low). The kVp signal will be very noisy so that some form of filtration or frequency limiting is required.

An external ion chamber type of radiation meter may be used to read radiation output, such as the Nuclear Associates Rad-Check Model 06-525. Other ion chamber and electrometer combinations will function just as well if the ion chamber is 20 to 100 cc volume and compensated for energies in the range of 30 to 110 keV. Meters for the direct reading of effective kV are also useful. Such meters include the Nuclear Associates Model 06-570 and the Radiation Measurements Inc. Model 230. These meters are positioned according to their instructions and test exposures are made. The output of the XRSLM normalized to 100 cm should be 4-6 mR/mAs at 80 kVp, the kVp should measure 75 to 85 kVp when set to 80 kVp, 100 to 110 kVp when set to 110 kVp, and 50 to 67 kVp when set to 60 kVp. Measurements of kVp taken from the internal resistors and external oscilloscope may vary depending on the skills of the observer. During testing, observe the relationships of exposure time and tube current. In particular, observe the change from 60 to 50 mA as the kVp is increased to 84 kVp and above, only if it possible to measure the actual exposure time (RMI Model 240 kVp meter with waveform monitoring or the Nuclear Associates Nero meters).

#### E. X-Ray Calibration

There are no provisions for adjustment of exposure time as these are incorporated in the program of the uP. X-ray tube anode current is determined by the filament settings. The 50 mA setting is done first with the 60 mA potentiometer turned down. Set the machine to 70 kVp and make a series of 10 mAs exposures. The actual kVp will be in error during these tests. Observe the mAs meter readings and set the 50 mA potentiometer R22 for 8 mAs at the mAs meter. Then set the 60 mA potentiometer R33 for 10 mAs at the mAs meter. Increase the kVp setting to 84 kVp and the test exposure should still read 10 mAs. It may be prudent to first set the adjustments slightly low, say 7 and 9 mAs respectively, until it is certain that the machine is performing properly.

#### F. Testing the Automatic Exposure Control

An 8" x 10" cassette should be used. The light field should be set to 8" x 10" and the size potentiometers in the cassette holder adjusted to just extinguish the "+" sign at the display. Repeat for the other cassette sizes. Later, confirm that the x-ray fields and light fields are congruent and adjust the collimator lamp as needed, then readjust the size potentiometers. The automatic exposure control is intended just for chest radiography. Select the center chamber and use a test phantom of 18 x 18 x 4 cm of EC 1100

aluminum, positioned close to the collimator as the absorber. Use a loaded 8 x 10 cassette and make an exposure. Set the density control for mean film density of 1.3 to 1.6 D. If this is not possible, adjust the trimmer capacitor on the circuit board and repeat the test. The trimmer is a rough adjustment and the density potentiometer is the fine adjustment. Blocking the phantom with a sheet of 1 mm lead should cause the AEC LCD display to flash and require the control to be reset indicating that the automatic exposure circuit failed to terminate the exposure.

## G. Miscellaneous Tests

Additional tests should be performed as required to assure that components remain capable of delivering full performance. The NiCd cells can fail gradually and not hold full charge. The energy storage capacitors can age and lose capacity. The x-ray tube can age through anode erosion and lose output as well as suffer catastrophic and obvious failure.

### 1. Battery Testing

The Power Unit must be partially disassembled. Remove the lead to the positive terminal of the battery assembly (most positive NiCd cell) and place a milliammeter in series. Plug in the 110 vac power cord with the S1 turned off and observe a normal charging current of 400 to 800 mA. When the cells are almost completely discharged, this current can be as high as 1500 mA for the first several minutes of charging then fall within the correct range. Continuous charging will not harm the cells. Check the voltage across each cell during charging. Each cell should be within 0.1 vdc of each other, around 1.25 volts each when not charging, around 1.45 volts when fully charged during charging. Disconnect the Power Unit from the power line and connect the battery to a load comprising either a 3 ohm 50 W resistor (combination of resistors or automobile headlamps totaling 50 W). Use an ammeter to verify the current. Check the voltage across each cell. The voltage should be between 1.00 and 1.20 vdc. Operate for 30 minutes with fully charged cells and check the voltage again. The voltage should be between 0.95 and 1.20 vdc/cell. The most common failure modes of NiCd cells are short-circuiting or failure to hold a charge. These cells are rated at 7.2 AH but under high loads in excess of 5 amp, their capacity falls to 5 AH. After the cells have been used for 250 cycles of charge/discharge or more than two years of use, their capacity may fall by 40%. Other types of low resistance batteries may be used if precautions are taken to assure that the battery is connected only to the system

ground terminals and that no "ground loop" exists. Such batteries include large dry cells, lead-acid gel cells, motorcycle type wet cells and most automotive lead-acid batteries. When using cells other than NiCd, charging voltage must be monitored to prevent over-charging. The internal charger will recharge other types of cells if this precaution is observed.

## 2. Capacitor Testing

The special electrolytic capacitors should have long life, lasting the full life of the XRSLM. However, capacitors may fail or dry out. Failure may be obvious by the appearance of electrolyte around the top vent holes of the capacitor case or by catastrophic failure which will be quite obvious. The circuit has a safety discharge circuit which uses a power FET and a load resistor to discharge the capacitor energy in several minutes when power is turned off. This circuit may be used as a capacitor test. Connect a voltmeter to the capacitors either directly or through pins H, I of J2. Turn on S1 either with battery power or with line power. Observe the charging time of the capacitors to +300 volts. If the capacitors have been recently charged, this time should be from 120 sec to 180 sec. If the unit has been stored for some time, this time will be from 120 sec to 300 sec. When the circuit is turned off, the safety discharge connects the charged capacitors to a 1k 50 W load. The total capacitance is 0.08 F so that the time constant of discharge is 80 seconds. Thus, the voltage should fall to 135 volts after the first minute, to 60 volts after the second minute, etc. Observe the voltages when timing with a watch to verify that the voltages do not fall faster than this rate.

## 3. Testing the X-Ray Tube

Standard focal spot tests may be made using AAPM Report No. 4 or NCRP Report No. 99. Output should be measured at 80 kVp, 10 mAs, 90 cm. The output should be about 6 - 7 mR/mAs and the half-value layer should be 3.0 mm Al. As the tube ages, the anode becomes rough and the output will fall and the half-value layer will increase. If the output falls below 4 mR/mAs with a rise of the half-value layer to above 3.5 mm Al and if the kVp has been measured to be between 78 and 82 kVp, it is probable that the tube should be replaced.

## H. Radiation Safety

The tubehead and collimator have been lined with lead to reduce radiation to the operators from those sources. When in use, assume that 10% of the incident beam times area will be scattered in all directions. Exit radiation is generally not significant. Operators should be aware that lead aprons only attenuate around 90% of their incident radiation. However, radiation falls as the square of the distance so that operators should be as far as possible from the patient and should try to position themselves on the exit side of the beam, i.e., it is safer to face the tubehead from behind the cassette holder than to be behind the tubehead. The cable of the Control/Display is long enough to permit the operator to get well away from the patient during exposure. If possible, a "ray-proof" barrier should be used to shield the operator. While leaded glass or leaded plastic is best, several thickness of common glass or a thick glass door or partition will reduce radiation to the operator by more than 75%. Distance, aprons, shielding and common sense are the best protection. All operators should wear a TLD or film badge to monitor their exposure.

## VII. Component Sources

The components of the XRS LM are of three types, standard commercial parts, items made from drawings and special parts including the transformers and some capacitors.

### A. Standard Components

<u>Item</u>	<u>Quantity</u>	<u>Reference</u>	<u>Part</u>
1	1	BT1	10 @ F NiCd Cells
2	4	C1, C2, C3, C4	0.02 F, 320 VDC, Mallory (Special) EAF203X320Y5R3PD
3	13	C5, C12, C16, C19, C35, C40, C47, C58, C62, C64, C68, C75, C89	4.7 uF, 16 VDC, tantalum
4	13	C6, C7, C18, C20, C34, C41, C52, C53, C54, C55, C56, C84, C88	0.01 uF, 100 VDC, mylar radial
5	1	C72	0.01 uF, 630 VDC, metalized poly
6	8	C8, C13, C44, C45, C46, C59, C60, C69	470 uF, 16 VDC, Al electrolytic
7	2	C9, C15	0.001 uF, 100 VDC, disc
8	4	C14, C36, C39, C49	0.0022 uF, 100 VDC, mylar radial
9	2	C10, C11	0.0022 uF, 630 VDC, metalized poly
10	7	C17, C38, C78, C80, C81, C82, C83	0.1 uF, 100 VDC, mylar radial
11	4	C21, C26, C27, C32	4000 pF, 12 KVDC, Cera-mite
12	4	C22, C25, C28, C31	3 @ 4000 pF, 12 KVDC, Cera-mite
13	4	C23, C24, C29, C30	5 @ 4000 pF, 12KVDC, Cera-mite
14	3	C33, C51, C63	0.022 uF, 630 VDC, metalized poly
15	2	C37, C42	1000 uF, 16 VDC, Al electrolytic
16	1	C43	1200 pF, 100 VDC, disc
17	1	C48	20 uF, 200 VDC, Cornell-Dubilier, 935C2W20K
18	1	C50	0.05 uF, 100 VDC, mylar radial
19	1	C57	50 uF, 25 VDC, Al electrolytic
20	2	C61	22 uF, 16 VDC, Al electrolytic
21	1	C65	0.047, 100 VDC, mylar radial

22	1	C66	1.0 uF, 400 VDC, Cornell-Dubilier, 935C4W1K
23	4	C79, C85, C86, C87	1.0 uF, 16 VDC
24	1	C67	47 pF, ceramic adjustable
25	2	C70, C71	0.005 uF, 100 VDC, mylar radial
26	2	C73, C74	33 pF, 500 VDC, ceramic disc
27	1	C76	47 uF, 16 VDC, Ta electrolytic
28	1	C77	10 uF, 16 VDC, Ta electrolytic
29	1	CB1	15 A, P&B W58XB1A4A-15
30	1	CB2	2 A, P&B W58XB1A4A-2
31	1	D1	Motorola MUR 815
32	12	D2, D3, D4, D5, D6, D7, D8, D9, D10, D11, D12, D13	IEP DMX1019 (20 kV/100 mA)
33	2	D14, D15	1N4937
34	2	D16, D17	1N5277B
35	5	D18, D19, D20, D21, D22	1N5821
36	1	D23	1N3913
37	2	D25, D34	1N5235
38	6	D24, D26, D27, D28, D29, D30	1N4148
39	2	D31, D32	1N5235B
40	1	D33	4 @ 1N4003
41	1	D35	1N4681
42	3	D36, D37, D38	HLMP-D101, Low Current LED
43	1	J1	115 VAC Plug (Power Cord)
44	1	J3	DT 07H-14-12PN, Deteronics
45	1	J4	Connector Edge 18
46	1	J5	Connector Edge 2 X 10
47	1	J6	MS3116F10-6P
48	1	J7	MS3102E20-16S
49	1	J8	26-159-16
50	4	JP1, JP2, JP3, JP7	Header 8, Wieland 8113S/8G0B
51	3	JPB1, JP4, JP6	Header 5, Wieland 8113S/5G0B
52	1	JPA1	Header 4, Wieland 25.104.0453
53	1	K1	P & B RKS-5DG-12
54	1	K2	P & B RKS-5AW-120

55	1	L1	4229 Pot Core
56	1	L2	2616 Pot Core, 1mm Gap
57	4	L3, L6, L7, L10	1.5 mH
58	1	L4	20 uH
59	1	L5	470 uH
60	1	L8	6656P 3C8 Pot Core, 0.25" Cap
61	1	L9	10 uH
62	2	LCD1, LCD2	LCD Display, Digi-Key #LCD002
63	4	LCDA1, LCDB1, LCDA2, LCDB2	LCD socket, 20 pin Molex strip
64	1	LP1	Neon Lamp
65	1	LP2	Sylvania Lamp #2011
66	1	MOV1, MOV2	MOV 22 V
67	1	MOV3	V150ZAB
68	6	Q1, Q2, Q3, Q4, Q5, Q6	MTH15N40
69	9	Q7, Q8, Q13, Q14, Q15, Q16, Q18, Q19, Q21	IRF540
70	3	Q9, Q10, Q22	IRF9531
71	1	Q11	SM600
72	2	Q12, Q17	VN10KM
73	1	Q20	2N3904
74	2	Q23, Q26	IRF530
75	1	Q24	D64EV7
76	1	Q25	IRF740
77	1	R1	1K, 50W
78	1	R2	68K
79	23	R3, R4, R21, R26, R27, R28, R32, R34, R44, R45, R52, R55, R65, R66, R67, R71, R72, R74, R75, R76, R78, R133, R137	4.7K
80	8	R7, R8, R9, R10, R11, R12, R13, R14	2.2 Ohm, 3W
81	2	R5, R6	4.7 Ohm
82	1	R20	22 Ohm
83	1	R86	0.01 Ohm, 5W, Dale non-inductive

84	2	R15, R16	100 Ohm
85	1	R17	18K
86	1	R7SIP1	10K SIP
87	18	R18, R23, R50, R51, R95, R96, R97, R100, R101, R102, R103, R104, R105, R106, R107, R108, R121, R122	10K
88	8	R19, R24, R31, R46, R47, R49, R77, R127	47K
89	1	R22	50K, pot, 20 turn
90	1	R25	680 Ohm
91	4	R29, R30, R136, R141	27K
92	1	R33	250K, pot, 20 turn
93	11	R34, R59, R60, R85, R94, R98, R99, R120, R123, R124, R143	100K
94	2	R145, R146	100K pot. AB WRA1GO56S104U
95	7	R35, R36, R37, R38, R39, R40	1000M, tubehead, Murata 20 kV, flat
96	1	R125	1000M, AEC, Victoreen, 1/2 w
97	4	R41, R92, R93, R144	4.7M
98	2	R42, R82	270 Ohm
99	1	R48	220K
100	1	R53	330K
101	3	R54, R90, R119	120K
102	2	R56, R62	15K
103	1	R57	150K
104	1	R58	180K
105	2	R61	1K
106	1	R126	1K, pot
107	1	R63	120 Ohm
108	1	R64	33 Ohm
109	1	R68	2.2K
110	1	R69	62K
111	1	R70	22K
112	1	R73	1.8K
113	3	R79, R128, R131	470K

114	2	R80, R132	2.7K
115	2	R81, R140	8.2K
116	1	R83	2.2 Ohm, 5W
117	1	R84	100 Ohm, 2W
118	1	R87	47 Ohm
119	1	R88	10 Ohm
120	1	R89	1.2K
121	1	R91	56K
122	9	R109, R110, R111, R112, R113, R114, R115, R116, R117	20K, pot, 20 turn
123	2	R118, R134	3.9K
124	2	R129, R130	5 Ohm, 5W
125	1	R135	39K
126	3	R138, R139, R142	330 Ohm
127	1	S1	PWR SW
128	5	S2, S4, S5, S6, S7	CASSETTE SIZES
129	1	S3	CASSETTE PRESENT
130	1	S8	TIMER PUSHBUTTON
131	1	SW1	2RSW5 Ceramic Rotary
132	1	T1	Craemer A2277 9036
133	1	T2	TDK X30 H6A
134	1	T3	3622 Pot Core
135	1	T4	2616 Pot Core
136	1	T5	FP16-750
137	1	U1	SG3527
138	2	U2, U12	SG3524
139	3	U3, U4, U10	SG3525
140	2	U5, U6	4011
141	2	U7, U15	CA3260
142	1	U8	78L05
143	1	U9	CA3160E
144	1	U11	LM2575-5.0
145	1	U13	HCPL-2211, Opto-isolator
146	1	U14	4052
147	1	U16	LM78L05
148	1	U17	LM317LZ

149	1	U18	4049
150	1	U19	TLC272CP
151	1	U20	4N26
152	1	U21	8751
153	1	U22	74LS138
154	1	U23	DAC0832
155	1	U24	ICM7211AM
156	2	U25, U27	4070
157	1	U26	74LS08
158	1	U28	74LS02
159	1	U29	74HC573
160	1	U30	TLC2201
161	1	U31	LM555
162	1	V1	X-RAY TUBE, Eureka 3-OIDCH
163	1	W1	COAX
164	1	Y1	Crystal, 3.686Mhz

Note: Common resistors all 0.5W/5% unless shown otherwise.

## B. Transformers/Inductors

1. High Voltage, Cramer Transformer Part No. 9036
2. Filament Trans., Core TDK X30-H6A, Pri 10CT, 24 AWG, Sec 3t Belden 8868
3. Charger Trans., Magnetek FP16-750
4. Cap. Charger Ind., Core 3019 3B7, 1mm gap, 8t 18 AWG
5. Cap. Charger Trans., Core 3622 3B7, pri 16t CT 24 AWG bifilar, sec 150 t 30 AWG
6. Pwr Sw Reg Ind., Core Ferroxcube 6656P, 6 mm gap, 156t 16 AWG, adj. gap for 600 uH +/- 10%
7. Test Transf., Core TDK H7C1, Pri 20t CT, 7str 20 awg, sec 20t 16 AWG
8. Filament Ind., Core 2616 3B7, 1 mm gap, 49t 24 AWG

## C. Capacitors

1. Energy Storage, Mallory Canada 0.02 F/315 vdc
2. Voltage Multiplier A, 4000 pf, 12 kV nominal, 20 kV test, right handed
3. Voltage Multiplier B, 4000 pf, 12 kV nominal, 20 kV test, left handed

## D. Special Components

1. Bellows Assembly, Parker Hannifin, PN61170-1 (UWISC)
2. Collimator, Collimaster, must be modified, add 1 mm Pb inside cover, change bulb, add, parts, etc., per dwg.
3. X-Ray Tube, Eureka 3-OID-CH, Brand Xray BX-4 1.4

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#### B. Patent Applications

The Cassette Holder mechanism and certain circuits of the XRSLM may be patentable. US Patent No. 5,11,493 May 5, 1992 has been issued on the basic circuits of the system and on a special tube developed (but not used).

#### C. Commercial Uses and Licensing

The compactness, ease of transport, and relatively low cost of manufacture should make the XRSLM an ideal machine for many commercial settings, including; hospital mobile units, small clinics and nursing homes, emergency disaster sites, sports arenas, horse and dog tracks, and veterenarian offices.

A number of companies have expressed interest in manufacturing the XRSLM for the military and for commercial applications. The X-cel X-Ray Company of Crystal Lake, IL, has purchased a license through the Wisconsin Alumni Research Foundation (WARF). In addition to the license fee, this company will pay royalties to WARF for commercial products sold using the XRSLM technology. Companies building machines using the XRSLM technology for US Military contracts are exempt from licensing and royalty fees.